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PRELIMINARY ECONOMIC IMPACT ASSESSMENT OF POSSIBLE REGULATORY ACTION TO CONTROL ATMOSPHERIC EMISSIONS OF SELECTED HALOCARBONS

ARTHUR D. LITTLE, INCORPORATED

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

SEPTEMBER 1975

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The report identifies relative economic impacts, on affected industries, of possible regulatory action to control atmospheric emissions of selected halocarbons. Emphasis is placed on five halocarbons: chlorofluorocarbons 11, 12 and 22, and chlorocarbons, carbon tetrachloride and methyl chloroform. As background the report provides information on U.S. and world production, use and atmospheric emissions of fifteen halocarbons. The report also examines alternatives for emission abatement and the conversion timetables required for abatement. Finally, a description of industry structure, including approximate sales and employment levels for affected sectors, is presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Aerosol generators	Earth atmosphere		
Air conditioning	Fluorohydrocarbons	Aerosol propellants	
Air Pollution	Freons ®	Atmospheric emissions	
Blowing agents	Halohydrocarbons	Economic impact	
Chlorohydrocarbons	Ozone	Stratospheric ozone	
Chloromethanes	Refrigerants		
Dry cleaning	Solvents		

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September 1975

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PREFACE

This report is a preliminary economic impact assessment. It is not a detailed quantitative analysis of the economic consequences of halocarbon regulation. The purpose of the report was to identify those industries which would be adversely affected by such regulation--should it become necessary--and to prioritize them for purposes of further analysis. The report provides background information for such further analysis.[a] Although the limited number of interviews was insufficient to establish statistically valid responses, the information presented is believed to be reasonably accurate and complete.

The scope of this study did not include an assessment of the ozone depletion hypothesis and no judgment on this question should be inferred anywhere in the report.

Statements in the report that alternatives are available to current uses of halocarbons do not imply that such substitutes should occur without strong justification. Furthermore, conducting a preliminary economic impact assessment does not imply that substantial benefits would or would not result from restrictions on the chemicals being considered. Further analysis of both the costs and benefits of such restriction should be undertaken.

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[a] Such analyses are currently underway under other contracts administered for example by the Environmental Protection Agency and the National Science Foundation.

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I. SUMMARY

A. INTRODUCTION

After a four-month review of available information, the Federal Task Force on Inadvertent Modification of the Stratosphere (IMOS) has concluded that "fluorocarbons released to the environment are a legitimate cause for concern."[a] The fluorocarbons are a class of commercially important chemicals -- used chiefly as aerosol propellants and refrigerants. They are also used as specialty solvents, in the manufacture of plastic foam, and in a variety of other minor ways. In June 1974, two scientists reported[b] their contention that human health and welfare may be seriously threatened by the accumulation of certain stable halogen-containing organic chemicals in the atmosphere. According to their theory, these chemicals may undergo photochemical decomposition in the upper atmosphere which, in turn, may lead to depletion of the Earth's ozone layer and a concomitant increase in the intensity of solar ultraviolet radiation reaching the Earth's surface. A possible threat may lie in the biological and climatological effects of this increased radiation. In any event, most scientists agree that there are important uncertainties in the current theory and that further research and analysis is required before conclusions may be drawn.

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[a] "Fluorocarbons and the Environment," sponsored by the Council on Environmental Quality and the Federal Council for Science and Technology, June 1975.

[b] Molina, M.J. and F.S. Rowland, "Stratospheric Sink for Chlorofluoromethanes: Chlorine Atom Catalyzed Destruction of Ozone," Nature, 249: 810, 1974.

The Strategies and Air Standards Division of the U.S. Environmental Protection Agency (EPA) asked Arthur D. Little, Inc. (ADL) to develop estimates of U.S. and world production of fluorocarbons and chlorocarbons and estimates of their emissions to the atmosphere, and to make a preliminary assessment of the economic impact resulting from restricting the use of five primary chemicals in the United States. The results of the analysis are reported herein.

B. PURPOSE AND SCOPE

1. Purpose

The ADL project had four primary purposes:

1. Develop background information relating to 24[a] halocarbons[b] (15 of which are commercially important), including U.S. and world production, use, and emissions to the atmosphere.
2. Identify and evaluate emission control strategies for five halocarbons identified by EPA as those most importantly involved in the ozone depletion theory at this time. For the uses of the

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[a] See Table III-3 for a complete listing of these chemicals.

[b] "Halocarbons" are halogen-containing hydrocarbons. The chlorofluorocarbons ("fluorocarbons") and the chlorocarbons are classes of halocarbons. Throughout this report, "F" is used as an abbreviation for "fluorocarbon." The industry numbering code (C-1, H+1, F) is used to designate specific fluorocarbons.

chemicals as aerosol propellants, refrigerants, plastic foam blowing agents and solvents, the potential was examined for substituting other chemicals, substituting products not using the chemicals, and reducing the emissions by upgrading equipment components and maintenance procedures and by installing vapor-recovery equipment.

3. Identify industry sectors which could be affected by control of production or use of the five halocarbons.
4. Categorize the economic impact expected to be experienced by each industry sector under a range of regulatory scenarios.

2. Scope

Although two fluorocarbons (F-11 and F-12) have been the subjects of greatest concern in the published discussions of potential effects on the ozone layer, other halogen-containing compounds may also be a cause for concern. For this reason, the current uses of 15 halogen-containing compounds were defined.

This report identifies industry sectors which would be affected by possible regulatory action levied to control atmospheric emissions of selected halocarbons. Although a detailed economic impact assessment has not been attempted, potentially impacted sectors have been identified and the level of economic impact likely to be experienced by the sectors has been categorized. The analysis was preliminary in the sense that a relative, rather than an absolute, economic impact assessment was undertaken.

The evidence of a possible threat to atmospheric ozone has been discussed extensively in the literature. However, the scope of this report does not include an assessment of this evidence. The possible economic benefits, if any, in reducing halocarbon emissions to the atmosphere have not been considered. Statements in the report that alternatives are available to current uses of halocarbons do not imply that substitutions should occur without strong justification, since some compromise in terms of performance or safety may be involved -- as well as some level of economic disruption.

This report focuses on five compounds which, if the ozone depletion theory is correct, are among those which could pose a threat to the Earth's ozone layer. Studies currently underway may disprove the ozone depletion theory or may add other compounds to the list of those considered as potentially contributing to ozone depletion. The five compounds suggested by EPA were fluorocarbons 11, 12, and 22 (which, according to one theory, may prove to be an environmentally preferred alternative to F-11 and F-12), and two chlorocarbons -- carbon tetrachloride and methyl chloroform. The other 19 chemicals are produced in relatively small amounts, or are believed by stratospheric scientists either to decompose in the lower atmosphere or to be produced naturally in amounts greatly exceeding man-made production.[a]

C. APPROACH

The approach used in preparing this report involved the collection of publicly available statistical information supplemented by interviews with representatives of some 28 companies and associations. While information in this report derived from these interviews is believed to be accurate, no inference should be made that related statements in the report are based on a statistically valid survey.

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[a] Carbon tetrachloride and methyl chloroform may also be produced naturally in the environment, according to some scientists.

In order to make a preliminary assessment of potential economic impact, ADL and EPA personnel developed nine hypothetical regulatory options divided into three implementation time frames: six months, three years; and six years. The options further differentiated among controls on production, emissions, and sales.

Based upon current estimated emission levels and estimated atmospheric stability, two groups of chemicals were identified to which the regulatory restrictions were applied. The first group, which represents those chemicals having the longer atmospheric residence times, consisted of F-11, F-12, and carbon tetrachloride. The second group consisted of the chemicals in the first group plus F-22 and methyl chloroform. The application of the nine regulations to two groups of chemicals produced 18 different regulatory options. The hypothetical regulations and the inclusion of the particular chemicals in the analysis have no official standing as proposed regulations.

D. MAJOR FINDINGS[a]

Table I-1 summarizes the estimates of production, atmsopheric emissions, and stability of the five primary compounds. Table I-2 lists the emissions from the chemicals' primary uses. The categorization of

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[a] This summary of findings is not represented as presenting a sufficient data base upon which to base important long-term decisions.

Table I-1. ESTIMATED WORLD AND U.S. PRODUCTION AND ATMOSPHERIC EMISSIONS OF FIVE PRINCIPAL HALOCARBONS - 1973

Halocarbons	World production, (thousands of metric tons)	U.S. production, (thousands of metric tons)	World emissions, (thousands of metric tons)	U.S. emissions, (thousands of metric tons)	Lifetime in the atmosphere
Fluorocarbons[a]					
F-11	930	150	700	140	greater than 10 years
F-12		220		170	
F-22	120	60	60	28	1 to 10 years
Subtotal	1,050	430	760	340	
Chlorocarbons[b]					
Carbon tetrachloride	950	470	40	20	greater than 10 years
Methyl chloroform	420	250	320	200	1 to 10 years
Subtotal	1,370	720	360	220	
Total[c]	2,420	1,150	1,120	560	

a. Production of F-11, F-12, and F-22 accounts for approximately 90 percent of total fluorocarbon production.

b. Production of carbon tetrachloride and methyl chloroform accounts for 8 percent of total U.S. production of commercially important chlorocarbons. Vinyl chloride represents 28 percent. Emissions of the other chlorocarbons are not presented here because of their shorter atmospheric life.

c. Values may not add due to rounding.

Sources: Arthur D. Little, Inc., production and emission estimates. Atmospheric lifetime estimates by Cicerone, et al., "Stratospheric Ozone Destruction by Man-Made Chlorofluoromethanes," Science, Vol. 185 (27 September 1974), p. 1165 and references contained therein, and A.P. Altshuller, EPA (personal communication).

Table I-2. ESTIMATED U.S. ATMOSPHERIC EMISSIONS FROM POTENTIALLY CONTROLLED CHEMICALS - 1973
(thousands of metric tons)

			Estimated annual emissions from use and disposal					
Chemical	Production	Production, transport and storage losses	Propellant	Refrigerant	Solvent	Blowing agent	Use as intermed. chemical	Total
Chemical Group 1								
F-11	150	1.5	107	5	small	13	-	125
F-12	220	2.2	113	59	-	3.4	-	180
Carbon tetrachloride	470	7.1	-	-	10[a]	-	3.8	20
Subtotal	840	11	220	64	10	16	3.8	325
Chemical Group 2								
F-22	60	0.6	small	27	-	-	small	28
Methyl chloroform	250	2.5	-	-	195	-	small	200
Subtotal	310	3.1	small	27	195	-	small	225
Total[b]	1,150	14	220	91	205	16	3.8	550

a. Predominently from use in pesticides.
b. Values may not add due to rounding.

Source: Arthur D. Little, Inc., estimates.

potential economic impacts resulting from the application of nine alternate regulations for reducing emissions of the three most stable compounds (F-11, F-12, and carbon tetrachloride) is shown in Table I-3. The major findings of the report are listed below:

- Total world production of the three primary fluorocarbons and chlorocarbons with estimated atmospheric lifetimes of more than ten years was 1.9 million metric tons in 1973. World production of the two primary chemicals with lifetimes of one to ten years was 540,000 metric tons.

The United States accounted for approximately 45 percent of the world production of fluorocarbons 11 and 12 and carbon tetrachloride. The U.S. production of fluorocarbon 22 and methyl chloroform was about 55 percent of world production. European production of the two chemical groups was approximately 40 percent and 30 percent respectively of world production. World emissions of carbon tetrachloride were only about 5 percent of world F-11 and F-12 emissions.

- Total world emissions to the atmosphere of F-11, F-12, and carbon tetrachloride were about 740,000 metric tons in 1973 (40 percent of production). World emissions of F-22 and methyl chloroform were 380,000 metric tons (75 percent of production).

The geographical distribution of emissions approximately equals the production distribution. Propellant uses of the chemicals with atmospheric lives greater than ten years resulted in 70 percent of their atmospheric emissions, and refrigerant uses accounted for 20 percent. Eighty-six percent of total F-22 and methyl chloroform emissions were produced by solvent uses of the methyl chloroform. Refrigerant uses of F-22 resulted in 13 percent of total atmospheric emissions for these two chemicals.

Table I-3. SUMMARY OF ESTIMATED ECONOMIC IMPACT ASSESSMENT
RESULTING FROM RESTRICTION ON U.S. USE OF F-11, F-12 AND CARBON TETRACHLORIDE

			Impact Sectors						
				Propellant applications				Non-propellant applications	
				Aerosol industry					
	Sector size related to controlled chemicals 1972/1973		Basic chemical producers	Independent fillers	Can manufactures	Valve manufactures	Aerosol marketers	Air conditioning and refrigeration manufacturers	Plastic foam producers
	Approximate production value ($millions)		$360	$130	$300	$60	$1,000	$7,000	$600
	Employment (thousands)		3	7	2.5	2	7.5	150	35
	Regulatory options	Emission reduction[a]							
6 months	1.	92%	2-3	1	3	1	2	1	2
	2.	82%	3	1	3	1	2	4	3
	3.	70%	3	1	3	1	2	5	4
	4.	80%	3	1	3	1	2	4	3-4
3 years	5.	83%	3	2-3	5	2-3	3	1-2	3
	6.	74%	3	2-3	5	2-3	3	4	3
	7.	63%	3	2-3	5	2-3	3	5	4
	8.	69%	3	2-3	5	2-3	3	5	4
6 years	9.	54%	5	3-5	5	3-5	5	5	4

REGULATORY OPTIONS

1. Ban all but replacement uses of controlled chemicals after six months
2. Regulation of non-propellant uses and ban of propellant uses after six months
3. No regulation of non-propellant uses and ban of propellant uses after six months
4. Government control of total chemical production after six months
5. Ban all but replacement uses of controlled chemicals after three years
6. Regulation of non-propellant uses and ban of propellant uses after three years
7. No regulation of non-propellant uses and a ban of propellant uses after three years
8. Government control of total chemical production after three years
9. No regulation of non-propellant applications and ban of propellant uses after six years

IMPACT CODE*

1 - severe
2 - substantial
3 - moderate
4 - limited
5 - essentially none

*See Chapter VII of report for definition of terms.

[a] Percent reduction in U.S. F-11, F-12, and carbon tetrachloride emissions to the atmosphere over a 20 year period beginning in 1976. A 5 percent demand growth is assumed in the absence of controls; no restriction on critical propellant uses (5 percent of total), a 5 year half-life for refrigerants and 50 percent control of emissions from plastic foams are assumed.

Source: Arthur D. Little, Inc., estimates.

- If the majority of the longer lived emissions are to be ended, the use of F-11 and F-12 as propellants must be greatly reduced. Significant emission level reductions may be achieved from the other use categories of the fluorocarbons and chlorocarbons by upgrading equipment components and by improved maintenance practices.

The total projected emissions of F-11, F-12, and carbon tetrachloride over a 20-year period could be reduced by 75 percent should propellant uses of F-11 and F-12 be banned after three years and the equipment using them as refrigerants and blowing agents be modified to reduce or recover losses to the atmosphere. An immediate end of emissions is not possible due to leakage from previous charges of refrigeration and air conditioning equipment with F-11 and F-12.

- Identifiable alternatives exist for the fluorocarbons and chlorocarbons or for the major products in which they are now used.

For many important uses of the chemicals, a conversion time of one to five years would be necessary before alternative products could be produced in adequate quantities. In some cases, conversion times of up to ten years may be required. While the substitute products will perform the primary functions of the chemicals or products using the chemicals, the substitution may result in different (often less desirable) cost or performance characteristics.

- A ban of propellant uses of F-11 and F-12 after three years would most strongly impact certain components of the aerosol industry, such as contract can fillers and aerosol valve manufacturers. A ban of other uses of F-11 and F-12 after three years would seriously affect major segments of the refrigeration industry.

A ban of all uses of F-11 and F-12 after six months would severely impact the refrigeration industry and segments of the aerosol industry and the foam products industry. Requirements for improved vapor recovery from non-propellant uses of the chemicals would, in almost all instances, have only slight economic impact.

E. CHAPTER SUMMARIES

In addition to the major findings of this study summarized above, the following is a synopsis of Chapters II-VII. It is important to recognize that in preparing the chapter summaries, generalizations have been made in the interest of greater ease of understanding; thus, statements in the summaries do not fully explain the complexities of the study on a given point.

1. Chapter II-Halocarbon Production and Use

A summary of U.S. and world production of the five primary compounds (F-11, F-12, F-22, carbon tetrachloride, and methyl chloroform) is presented in Table I-1. Similar information for the remaining commercially important halocarbons is discussed in Chapter II. Estimated world production of fluorocarbons 11 and 12 exceeded 900,000 metric tons in 1973. U.S. production of these two fluorocarbons represents approximately 40 percent of the world total. Of the five principal compounds, carbon tetrachloride is the single most important in terms of production volume; however, nearly all of this production is used in the manufacture of fluorocarbons 11 and 12. Applications of the three fluorocarbons (F-11, F-12, and F-22) as propellants and refrigerants are by far the most important, accounting for approximately 80 percent of total demand for these compounds. The primary use of methyl chloroform is as an industrial cleaning solvent. The major applications for the other commercially important halocarbons are as solvents and as chemical intermediates for the production of plastics and a variety of other materials.

2. Chapter III-Halocarbon Emissions to the Atmosphere

A summary of estimated U.S. and world emissions to the atmosphere of the five key compounds of interest is presented in Table I-1. Estimated world emissions of fluorocarbons 11 and 12 were 700,000 metric tons in 1973. Estimated U.S. emissions of these two fluorocarbons in 1973 amounted to 310,000 metric tons, or approximately 45 percent of the total world emissions. Worldwide emissions of fluorocarbon 22 are small by comparison -- about 60,000 metric tons. The major source of U.S. and world fluorocarbon emissions to the atmosphere is the use of the chemicals as propellants in aerosols.[a] This emission source accounts for an estimated 60 percent of total world emissions. Fluorocarbon emissions from refrigeration and air conditioning equipment are second in importance to those from aerosols, accounting for approximately 25 percent of total world emissions. Within these two fluorocarbon emission categories, the largest subcategories are personal care aerosols (mainly hairsprays and antiperspirants) and air conditioners (chiefly mobile and large commercial units) respectively.

3. Chapter IV-Analysis of Major U.S. Emission Sources and Alternatives for Emmision Abatement

The opportunities for substituting other chemicals or products for the five principal chemicals are presented in Table I-4. The table also

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[a] F-22 use in aerosols is negligible.

Table I-4 SUBSTITUTION ALTERNATIVES AND EMISSION REDUCTION POSSIBILITIES FOR FIVE PRIMARY CHEMICALS

Chemical	Major chemical uses	Emission control opportunities	
		Substitute chemical or product alternatives	Emission reduction alternatives
Fluorocarbons (F-11, F-12, & F-22)	Aerosol propellant	Substitute propellants or products	None
	Refrigerant	F-11 & F-12 to F-22, or F-11, F-12 & F-22 to other refrigerants or systems	Upgrade components Improve maintenance
	Blowing agent, other	Substitute blowing agents	Install vapor recovery equipment
Chlorocarbons Carbon tetrachloride	(predominently used in the production of F-11 and F12)	-	-
Methyl chloroform	Cleaning solvent	Other solvents	Install vapor recovery equipment

Source: Arthur D. Little, Inc., estimates based on industry contacts.

shows where emission reductions can be achieved as an alternative to banning the use of the chemicals.

In all of the end use categories reviewed above, with the exception of aerosol propellant applications, emission control and recovery appears to be an effective means of significantly reducing emissions of fluorocarbons F-11, F-12, F-22, and methyl chloroform. Carbon tetrachloride emissions are already relatively small and are derived mainly from manufacture of F-11 and F-12. Carbon tetrachloride emissions should therefore be reduced in proportion to the reduced demand for F-11 and F-12 which would accompany reduced emissions of these compounds.

By the very nature of their use as aerosol propellants, emissions of F-11 and F-12 from this application can only be achieved through substitution of other propellants or other delivery systems. While no widely accepted propellant substitutes having similar cost/performance characteristics are now available (note discussion below), it appears that alternative products are available should it be required that the use of fluorocarbon aerosols be restricted or banned.

a. Aerosol Propellants - The greatest volume of fluorocarbon use (mainly F-11 and F-12) is in aerosol propellant and vapor depressant applications -- predominantly personal care products such as hairsprays and deodorants. The fluorocarbons' combination of appropriate vapor pressure, low toxicity, and non-flammability results in safe aerosol products with good consumer acceptance. Other lower cost propellants, such as compressed gases and hydrocarbons, are available and in use. However, these substitutes have not yet been widely accepted since they have different performance characteristics.

Non-aerosol products intended to serve markets now dominated by aerosol products have been available to consumers for some time. In the event of a ban of the fluorocarbon aerosols, the production of the non-aerosol products can be increased. However, since consumers have seen a difference between the non-aerosol and aerosol products, they may not completely convert to the non-aerosol products if the aerosol products are banned, and a net loss of industry sales may result.

b. Refrigerants - Large quantities of fluorocarbons (mainly F-12 and F-22) are also used as refrigerants in both small and large air conditioning, refrigeration and freezing systems. Most systems now manufactured using F-11 or F-12 could probably be redesigned (at a cost) to use F-22, if its emissions are shown to be acceptable. However, previous attempts to produce refrigeration equipment and automobile air conditioners using F-22 have not been successful. Other equally safe refrigerants are not available for use in the common vapor-compression systems now used in the majority of applications. However, other refrigerants may be more environmentally acceptable than the fluorocarbons if the ozone depletion theory is validated. Absorption refrigeration systems represent a possible long-term substitute to the fluorocarbon-based vapor-compression designs, and these systems may be good alternatives for some applications if the use of all fluorocarbons as refrigerants must be curtailed. On balance, the alternatives available for complete elimination of F-11 and F-12 emissions from refrigerant applications appear to be unattractive at this time.

If limited fluorocarbon emissions are acceptable, it appears that significant reductions in emissions to the atmosphere can be achieved by establishing new maintenance and repair procedures, redesigning certain equipment components such as tubing connectors and hoses on mobile systems, and recovering the refrigerant from discarded equipment. The economic impact on the producers and on product prices would be much less than that of a forced conversion to refrigeration systems not using fluorocarbons.

c. Foam-Blowing Agents - It appears that atmospheric emissions of fluorocarbons (mainly F-11) in plastic foam manufacturing may be eliminated by converting to use of methylene chloride as a blowing agent in flexible foams (which represent about 60 percent of F-11 foam use). While use of other blowing agents such as carbon dioxide and water in rigid foams is possible, the foams lose much of their insulating properties and thus their technical and economic competitive advantage.

The fluorocarbon vapors produced in making foam products are now vented to the atmosphere. It is possible that vapor-recovery equipment could be developed for recapturing the F-11, but such equipment is not now in existence.

d. Solvent Applications - Of the five primary chemicals examined in this study, only methyl chloroform has important solvent uses. It is used primarily as a metal cleaning solvent in both cold cleaning and vapor degreasing. There are several possible substitute solvents available; the major ones are: perchloroethylene, trichloroethylene, methylene chloride, and various fluorocarbon solvents. However, changing to any of these solvents can present some serious technical problems with equipment designed to use methyl chloroform. Other cleaning systems not using halocarbons are available, but are often more hazardous, less effective, or require more expensive operating equipment. Emissions may be greatly reduced in many cases by close adherence to recommended operating procedures.

Emission control is also possible using well-established solvent recovery systems or other control technology which can often pay for itself in several years by lowering make-up solvent costs.

4. Chapter V-Conversion Timetables

Whichever alternatives are chosen, there is a finite response time for upgrading equipment using the chemicals or for developing and introducing alternative chemicals and products. Table I-5 lists the estimated response time of the consuming industries to restrictions on the use of the fluorocarbons and chlorocarbons. The magnitude of economic disruption resulting from implementation of the alternative regulatory strategies is critically dependent on when the regulation is imposed and thus the response time available to chemical producers, substitute product producers, and the consumers of the chemicals. The conversion response times, which approximate the minimum time periods required for rapid yet minimally disruptive conversion to alternatives, may be of two types: conversion to a substitute chemical or conversion to an alternative product for satisfying the demand for products currently using the controlled chemicals. These response times could range from as short as one year for expanding production of existing products currently competing with products using the controlled chemicals to as long as ten years for the development, testing, and construction of manufacturing facilities for a totally new aerosol propellant.

5. Chapter VI-Definition of Primary Affected Industry Sectors

Ten primary industry sectors were examined in the ADL study. They ranged from the raw material producers to the sectors consuming the fluorocarbons and chlorocarbons. Table I-6 provides a summary

Table I-5 CONSUMING INDUSTRY RESPONSE TIMES TO CHEMICAL USE RESTRICTIONS

Consuming industry	Emission reduction by equipment upgrading (years)	Primary response to ban of chemical use[a] (years)		Conversion to substitute chemicals[b] (years)
		to absorption	to F-22	
Intermediate chemical applications	Not an option	2-7		5-10
Propellant applications	Not an option	1-2		4-10
Refrigerant applications [c]				
Appliances	2-3	4-6	3-4	5-11
Mobile air conditioners	3-4	Indefinite	Indefinite	5-11
Home air conditioners	2-3	3-5	zero	5-11
Commercial refrigeration	2-3	4-6	3-4	5-11
Commercial air conditioners				
- reciprocating	2-3	3-5	2-3	5-11
- centrifugal	2-3	2-3	1-3	5-11
Blowing agent applications				
Flexible foams	2-3	six months		six months
Rigid foams	2-3	3		4-9
Solvent applications	1	1-2		4-9

a. The primary response times are the elapsed times required for the consuming industries to introduce substitute products to meet the demand now satisfied by the controlled chemicals or products using the chemicals.

b. The conversion to substitute chemicals times are those required to develop new chemicals with properties similar to the banned compounds and to modify the products using the banned chemicals.

c. In the event of a ban of F-11 and F-12, most refrigerant applications could be converted to F-22. If F-22 is also banned, other refrigerants could be used or some products could be converted to absorption systems.

Source: Arthur D. Little, Inc., estimates based on industry contacts.

Table I-6. ESTIMATED EMPLOYMENT AND PRODUCTION VALUE RELATED TO FLUOROCARBON AND CHLOROCARBON PRODUCTION AND CONSUMPTION - 1973

	Total industry employment	Directly[c] related employment	Total industry production value 1973, ($, millions)	Directly related production value 1973, ($, millions)
Raw materials:				
Chlorine	10,300	1,350	490	60
Hydrofluoric acid	800	330	140	55
Basic chemical production:				
Fluorocarbons	2,700	2,700	240	240
Chlorocarbons	6,600	1,320	600	120
Aerosols:				
Containers[a]	68,200	2,500	4,900	190
Valves, caps & related materials	NA[b]	2,000	NA[b]	60
Concentrate ingredients	NA	NA	NA	NA
Aerosol fillers[d]	14,000	7,000	250	130
Aerosol marketers[d] (total)	15,000	7,500	2,000	1,000
Production	6,000	3,000	-	-
support (R&D, marketing, etc.)	9,000	4,500	-	-
Refrigeration: (1972)				
Refrigeration equipment	120,000	120,000	5,600	5,600
Household refrigerators & freezers	32,000	32,000	1,600	1,600
Blowing agent applications:				
Foam and derived products	45,000	30,000	1,000	600
Raw materials	10,000	5,000	460	230
Solvent Applications	NA	NA	NA	NA
Chemical intermediate	NA	3,000	NA	25

a. Includes only cans, which represent 95 percent of total aerosol containers.

b. NA = not available.

c. Related employment refers to production of F-11, F-12, F-22, carbon tetrachloride and methyl chloroform.

d. Directly related employment and production of aerosol fillers and marketers was estimated as 50 percent of total industry employment and production.

Source: Arthur D. Little, Inc., estimates.

characterization of these industry sectors. The employment values directly related to the production or use of fluorocarbons or chlorocarbons should not be regarded as an estimate of the jobs to be lost if the production of the chemicals is ended or reduced. Some of these jobs may be lost, but many would only be affected to the extent of having to use different chemicals or materials. Because of the preliminary nature of the impact analysis in this report, no attempt has been made to estimate job losses or gains as a result of restrictions in the use of the chemicals.

a. Raw Material Producers - The raw materials used in the production of chlorocarbons and fluorocarbons which were examined in the study are chlorine and hydrofluoric acid. They are the raw materials which have a significant portion of their production dedicated to the chlorocarbons and fluorocarbons. An estimated 13 percent (by weight) of chlorine demand, with a production value of approximately $60 million in 1973, is used in the production of the five primary chemicals: F-11, F-12, F-22, methyl chloroform, and carbon tetrachloride. An estimated 42 percent of hydrofluoric acid demand, with a production value of about $55 million in 1973, is consumed in the production of the three fluorocarbons -- F-11, F-12, and F-22. A large volume of the raw materials and basic chemicals is not sold on the open market but consumed by other segments of the producing companies. For this reason, "production values" have been estimated by applying market prices to all production--rather than reporting sales, which would understate the value of the chemicals produced by each firm.

In 1973, the value of the production of F-11, F-12, and F-22 was approximately $240 million, and the value of carbon tetrachloride and methyl chloroform was about $590 million. The sum of methyl chloroform, carbon tetrachloride, and the portion of chloroform production used to make fluorocarbons was an estimated 12 percent of total chlorocarbon value (including vinyl chloride) in 1973, or $120 million. Raw material and basic chemical production are capital-intensive operations and, as a result, related employment for the production of the five chemicals is relatively small at about 4,500 employees.

b. Aerosol Producers - Aerosol products had an estimated $2 billion manufacturer's value in 1973. About half of the 3 billion units were propelled by fluorocarbons. Approximately 60 percent of the aerosol products are filled by contract fillers; the remaining 40 percent are filled by the aerosol product marketers. The aerosol fillers are characteristically small companies whose business is heavily dependent on the filling of aerosol products. However, there are several large aerosol fillers which account for more than 30 percent of the industry filling capacity yet represent only 3 percent of the total number of firms. The aerosol marketers are generally large corporations who are much less dependent on aerosol products as their primary activity than are the aerosol fillers. Employment by contract fillers and my manufacturers of aerosol containers, valves, caps, and related materials, directly related to products using fluorocarbon propellants, is an estimated 11,500. In addition, an estimated 7,500 persons are employed by aerosol marketers in production, research and development, sales, and other support activities directly related to products using fluorocarbon propellants.

c. Refrigeration and Air Conditioning Industry - In terms of employment and production value, the refrigeration industry is the largest industry sector which would be significantly affected by restricting the use of the fluorocarbons. Production value of refrigeration equipment and household refrigerators and freezers was $7.2 billion in 1972. Directly related employment was 150,000 in 1972. In addition, an estimated 280,000 employees are indirectly related to the manufacture of air conditioning and refrigeration equipment, being involved in service, sales, and other related industries. The industry is characterized as mature, relatively concentrated, and highly competitive. Air conditioning and refrigeration equipment sales account for a large portion of the total sales of many firms in the industry. For some firms, such as the large automobile and appliance manufacturers, sales of refrigeration equipment and air conditioners do not represent a large portion of total corporate sales.

d. Foam Products Industry - Employment in the production of chemical raw materials used in the manufacture of foams and in the production of foam products themselves totals an estimated 55,000. The production value of foam products is approximately $1 billion. However, fluorocarbon blowing agents are used in the manufacture of only 60 percent of foam products, so the related foam production value and total employment can be estimated at approximately $600 million and 35,000 respectively. It is assumed that foam users would use an alternative product and would thus have few, if any, employment and sales effects.

e. Solvent Applications - Estimates of employment and production value have not been made for the users of the chemicals as solvents since they are so diffuse. The solvent users include the Defense Department, various metalworking shops, electronic component manufacturers, and many others. They cannot be classed as a single group, as has been done, for example, with the refrigeration industry.

6. Chapter VII-Initial Economic Impact Assessment

The categorization of the potential economic impacts resulting from implementing nine regulatory options for reducing atmospheric emissions of F-11, F-12, and carbon tetrachloride is shown in Table I-3. The application of the nine regulatory options to production and use of the less stable compounds (F-22 and methyl chloroform) is reported in Chapter VII.

The preliminary economic impact assessment shown in Table I-3 was developed by considering the following principal factors:

- The availability of substitute products to the major industry sectors now consuming the chemicals,
- The current dependence of the consuming sectors on the potentially controlled chemicals,
- The current availability of vapor-recovery or vapor-reduction technologies,
- The estimated elapsed time required for the industries now using the chemicals to convert to alternative chemicals, processes or products,
- The relative importance of the affected products to the overall business activities of which they are a part,

- The relative importance of the cost of the chemicals to final product prices,
- The degree to which the facilities producing the chemicals can be converted to non-regulated chemicals,
- The integration of the production of the chemicals, or products using the chemicals, into large complexes of unaffected production activities as opposed to plants primarily dedicated to the affected products, and
- The potential for threatening the viability of the producing firms as opposed to a small or moderate reduction in their sales.

There are six industry sectors which would primarily be affected by restrictions on the use of fluorocarbons and chlorocarbons:

- Producers of the chemicals,
- Firms using the fluorocarbons and chlorocarbons as chemical intermediates,
- Firms using the chemicals as propellants,
- Firms using the chemicals as refrigerants,
- Firms using the chemicals as blowing agents, and
- Firms using the chemicals as solvents.

For these six sectors, emission reduction strategies of two types have been considered. The first, which is not feasible for aerosol propellants, is to upgrade the equipment using the chemicals so that emissions to the atmosphere are reduced even though the chemicals continue to be used. For refrigeration and solvent uses of the chemicals, and probably blowing agent uses, significant emission reductions can be achieved using this approach. The second strategy (the only one feasible for propellant applications) is to require or encourage development and use of substitute chemicals or substitutes to the products currently using the chemicals. It is important to remember that for non-propellant applications, especially, this strategy involves a considerable investment in terms of added research and development.

The nine regulatory options summarized in Table I-3 were defined through discussions with the EPA and are intended to achieve a range of reductions of emissions to the atmosphere of the three compounds over a given time range. These potential regulatory strategies have no official standing; they are intended only to identify a range of alternatives and to enable a more specific discussion of the relative disruptions likely to occur in the six U.S. economic sectors shown. Other regulatory actions are possible and will undoubtedly be considered if a decision is made to reduce emissions.

The promulgation of a ban of all uses of F-11, F-12, and carbon tetrachloride after six months (regulatory option 1) would result in an estimated 92 percent reduction in the total projected U.S. emissions of the compounds over a 20-year period.[a] A ban of only propellant uses (option 3) would result in a 70 percent reduction in emissions to the atmosphere over the 20 years. If, instead of banning the uses after six months, the ban on all uses is set for three years after the January 1976 decision (option 5), then the emission reduction would be 83 percent instead of 92 percent. Imposing a ban on only propellant uses after three years (option 7) would produce 63 percent lower emissions. Option 9, a ban of propellant uses after six years, would result in a 54 percent emission reduction over the 20-year period.

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[a] On the assumption that the decision to issue the regulation is made in January 1976, the 20-year period runs from January 1976 to January 1996. A 5 percent per year use growth rate in the absence of the ban is assumed.

The regulatory alternatives have a range of potential economic impacts from "severe" to "essentially none"[a] on the seven industry sectors examined. A ban of propellant uses of F-11 and F-12 after six months would have a severe impact on contract fillers of aerosol cans and the manufacturers of aerosol valves. The impact on the aerosol marketers would be moderate. Postponing the ban for three years would reduce the potential impact on the fillers and valve manufacturers to a limited to moderate level, depending on consumer acceptance and availability of new aerosol products not using F-11 and F-12. With the ban held off for six years, the impact on the valve manufacturers and fillers is projected to range from limited to essentially none. However, announcement of a ban to be placed in effect in six years (or three years) could speed the change cycle considerably as marketers of the alternative products vie for market share. In this instance, the economic impact on the current manufacturers could be substantially greater than shown here.

A ban imposed on refrigeration uses of F-11 and F-12 after six months is expected to result in severe impacts on the refrigeration and air conditioning industry. A ban after three years could also be severe but is more likely to be in the moderate category. Products using substitute refrigerants or substitute refrigeration technologies could not be expected to be available for approximately three years -- and then only in limited quantities. Regulations which substantially increase the price of F-11 and F-12 or which require upgrading of the refrigeration equipment and maintenance in order to reduce emissions are not expected to have a detrimental effect on the producers beyond some modest increase in product prices.

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[a] See Chapter VII of the report for definition of these terms.

A ban of major uses of the chemicals after six months or three years is expected to have a limited impact on the viability of the chemical producers. While the regulations would end all or much of the production of the controlled chemicals, and some plant might even be closed, the value of the products represents less than 10 percent of the chemical sales of all but one producer. It is important to realize, however, that most halocarbon producers are integrated and that balances between raw materials and various products can be critical to efficient operation. The impact on this sector of the chemical industry could therefore be much greater than the level indicated when individual firms are considered.

The nine regulatory options can be ranked by their reduction in potential emissions and by potential economic impact on each industrial sector. Generally the ordering of the emission reduction and the economic impacts are in opposite directions. However, it is not possible to select an optimal regulatory option knowing only the emission reductions and the economic impacts. It is not known, for example, whether fluorocarbon emissions are a correct measure of potential impact on the ozone. The emission reductions cited above are over a 20-year period following a decision to ban the uses of the chemicals. As an alternative measure, an estimate is made in the report of the reduction in total emissions (measured from the time when the chemicals were first produced) as a result of initiating the regulatory options in 1976. Other ways of measuring emissions can be suggested, but a generally accepted approach has not yet been developed. Alternative methods would probably not change the ranking of the regulatory alternatives but would allow an identification of which regulations resulted in acceptable levels of emissions and a specification of the length of time before they were achieved.

Following from a need to define the correct measure of emissions is the need to quantify the benefits of reducing the level of emissions. The benefits would be the damages (if any) avoided by not having the ozone layer diminished. In order to select among the regulatory options, one must have some direct or indirect way of estimating the possible benefits of issuing the regulations. The incremental benefits must then be compared with the incremental costs which would result from implementing the regulations. The decision is much more complex than simply considering emission reductions versus a categorzation of economic impacts. The results of this report should be regarded as a partial information base and are not in themselves a sufficient data set on which to base long-term decisions.

In addition to developing measures of possible benefits coming from emission reductions, one must consider that if there is a danger to the ozone layer, it is a worldwide danger. U.S. halocarbon emissions account for only about half of current worldwide emissions. In addition, it is likely that the emissions growth rate will continue to be greater outside the United States. Thus, restrictions on U.S. emissions could affect only about half the current emissions and a diminishing share of world emissions in the future. If substantial reductions in worldwide emissions should become necessary, other countries will also eventually have to reduce atmospheric emissions of these compounds.

II. HALOCARBON PRODUCTION AND USE

A. INTRODUCTION

This chapter presents both U.S. and world production and end-use data for the compounds of interest. While data of this type are generally available (at least for the chlorocarbons) in the U.S., this is not the case for other regions of the world. Available data have been collected and, where necessary, estimates have been made of likely world data for ten commercially important chlorocarbons and for five major chlorofluorocarbons: F-11, F-12, F-22, F-113 and F-114.[a]

Based on the information presented in this chapter, it is possible to gain an appreciation for the major role played by the U.S. and Europe in the production and use of the compounds of interest. Together these two regions of the world share anywhere from 75 to 90 percent of the world's production of these chemicals. While the consumption share in these regions is probably somewhat lower because of exports to less industrialized regions of the world, it is certainly on the same order of magnitude as the production share.

End-use patterns, for most of the chemicals studies, are nearly the same throughout the world. Notable exceptions are the greater proportion of propellant applications for fluorocarbons in Europe relative to the U.S. and also wider use of trichloroethylene for metal cleaning outside the U.S.

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[a] Throughout the report, "F" is used as an abbreviation for "fluorocarbon;" the numbers (11, 12, etc.) are commonly used identification for specified compounds.

B. FLUOROCARBON PRODUCTION AND USE

1. United States

a. Production - United States production data for the five major fluorocarbons from 1960 to 1974 are presented in Table II-1. Fluorocarbons 12 and 11 are produced in greatest quantity, accounting for nearly 80 percent of total production in 1974. Fluorocarbon 22 represents approximately 13 percent of current production and all other fluorocarbons combined contribute less than ten percent of the total.

Production of these chemicals has increased greatly over the past decade—with the exception of F-114. Between 1964 and 1974, production of F-22 increased at an average compound rate of 9 percent per annum. Production of F-12 increased at a rate of approximately 8 percent per annum during the same period. The production increase between 1964 and 1974 for F-11 represents a growth rate midway between those of fluorocarbons 12 and 22. In contrast to these three compounds, F-113 has experienced very rapid growth (over 18 percent per annum) in the past ten years and F-114 has experienced only moderate growth since 1965.

United States fluorocarbon producers and their current capacities are presented in Table II-2. Of the six U.S. producers, DuPont has the largest capacity with 42 percent of the total, while Allied Chemical is second with 26 percent. Union Carbide, Pennwalt, Kaiser and Racon together, account for the remaining 32 percent. The completion and start-up of DuPont's 500 million pound fluorocarbon production plant in Corpus Christi, Texas, may be delayed indefinitely because of the questionable future of fluorocarbons. Total production in 1973 was equal to approximately 88 percent of reported capacity.

Table II-1. UNITED STATES FLUOROCARBON PRODUCTION DATA
(millions of pounds)

Year	F-11	F-12	F-22	F-113	F-114	Others[a]	Total
1960	72	165	40	Sm.	10	Sm.[b]	>287
1961	91	174	45	Sm.	Sm.	Sm.	>310
1962	125	208	49	Sm.	11	Sm.	>393
1963	140	217	54	Sm.	12	Sm.	>423
1964	149	228	59	12	13	Sm.	>461
1965	171	271	64	14	22	Sm.	>542
1966	170	286	70	16	19	Sm.	>561
1967	182	310	78	21	23	Sm.	>614
1968	204	326	86	25	20	Sm.	>661
1969	239	368	94	30	21	Sm.	>752
1970	245	375	100	36	22	Sm.	>778
1971	258	390	112	43	23	Sm.	>826
1972	300	439	123	50	25	Sm.	>937
1973[c]	334	489	136	59	26	12	1056
1974[c]	347	509	141	64	27	14	1102
1974 Percent of total	32	46	13	6	2	1	>9700 100

a. Includes F-13, F-14, F-21, F-115, F-116 and others.
b. Sm. = less than 10 million pounds.
c. One industry source believes production of F-11 and F-12 is overstated.

Sources: U.S. International Trade Commission and Arthur D. Little, Inc., estimates, based on industry contacts.

Table II-2. UNITED STATES FLUOROCARBON PRODUCTION CAPACITY[a] BY PRODUCER-1973
(units as indicated below)

Producer	Million lb/yr.	Thousand metric tons/yr.	Percent current national capacity
Allied	310	141	26
DuPont	500	227	42
Kaiser	50	23	4
Pennwalt	115	52	10
Racon	20	9	1
Union Carbide	200	90	17
Total	1,195	542	100

[a] Nameplate capacity based on published estimates.

Sources: Chemical Marketing Reporter and Arthur D. Little, Inc.

b. End Use - A distribution of fluorocarbon consumption by end use for the years 1963, 1968 and 1973 is presented in Table II-3[a]. Aerosol propellants have consistently been the major application throughout this period, consuming 49 percent of fluorocarbon production in 1973. The next largest use has been as refrigerants, while uses in the manufacture of plastics, as solvents, and in plastic foam blowing applications have each consumed between four and seven percent. Other small applications of fluorocarbons include use as fire extinguishing agents, dielectric fluids and cutting fluids.

Propellant applications of fluorocarbons are skewed heavily toward personal products such as aerosol anti-perspirants and hair sprays. These two products, along with deoderants, account for approximately 75 percent of fluorocarbon propellant use. The only other single application accounting for more than 3.5 percent of fluorocarbon propellant use is the medicinal and pharmaceutical product category which adds another 4 percent to the personal product total. Further details of propellant applications, as well as details of those uses discussed below, are presented in Chapter IV of this report.

Use of fluorocarbons as refrigerants is predominantly in air-conditioning applications, which account for over 85 percent of annual fluorocarbon consumption in this end-use category. The largest single use of fluorocarbon refrigerants is in various central air-conditioning units which consume approximately 30 percent of current annual use. Second largest, with approximately 25 percent is mobile(mainly automobile) air-conditioning. All other

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[a] For a graphic representation of fluorocarbon uses see Figure VI-2.

Table II-3. UNITED STATES FLUOROCARBON CONSUMPTION BY END USE (percent)

End use	1963	1968	1973
Aerosol propellants	49	45	49
Refrigerants	29	30	28
Plastics and resins	10	10	4
Solvents	2	5	5
Foam blowing agents	5	4	7
Exports and other	5	6	7
Total	100	100	100

Sources: Chemical Economics Handbook, Chemical Marketing Reporter and Arthur D. Little, Inc., estimates.

refrigerant use categories are relatively small, with only a few accounting for more than about 5 percent of annual refrigerant demand each.

Foam blowing agent applications are much smaller than the propellant and refrigerant uses discussed above. Rigid polyurethane foams (about 50 percent), and flexible polyurethane foams (about 40 percent) account for nearly all of the halocarbons[b] used in the manufacture of plastic foams. Thermoplastic foam manufacture accounts for about 20 percent of the total. These foam products are widely used in padding and insulation applications, and in the latter case, the fluorocarbon trapped in the foam adds to its insulating properties.

Solvent and polymer uses of fluorocarbons account for 5 and 4 percent of demand respectively. Earlier estimates of polymer use are believed to have been overstated. The key solvent applications are in the aerospace and electronics industries. Fluorocarbon polymers have unique properties which make them valuable in a number of special applications where a low coefficient of friction and chemical inertness are important.

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b. Approximately 90 percent of the halocarbons used as blowing agents are fluorocarbons.

2. World

a. Production - World fluorocarbon capacity and production data for 1973 are presented in Table II-4. United States capacity, at 542 thousand metric tons, represents 44 percent of the total. Europe, with a capacity of 500 thousand metric tons per year, accounts for an additional 41 percent of world capacity. Japan's fluorocarbon production capacity is approximately 100 thousand metric tons per year, which represents 8 percent of the total. Other regions of the world, including Latin America, Australia and the USSR are estimated to represent 7 percent of world fluorocarbon capacity.

Announced capacity expansion plans, if implemented, would raise total world capacity to approximately 1.6 million metric tons by 1977/78. This represents a world compound growth rate of 6-7 percent per annum. Actual unrestricted world demand growth for these compounds is forecast to be approximately 8-9 percent per annum over the next five years. Current atmospheric concerns may restrict this growth. Fluorocarbons 11 and 12 represented an estimated 86 percent of world fluorocarbon production in 1973.

b. End Use - Table II-5 presents estimated world consumption by end use for fluorocarbons. Consumption in other parts of the world is believed to approximate the pattern seen in the United States. As in the United States, aerosol propellants constitute the primary use of fluorocarbons. Refrigerants are second in terms of total fluorocarbon consumption, while plastic foam blowing is third, and solvents and plastics are fourth and fifth most important respectively.

Table II-4. WORLD FLUOROCARBON PRODUCTION AND PRODUCTION CAPACITY-1973
(thousands of metric tons)

Region	Estimated capacity	Estimated production	Percent of total
United States	542	475	44
Europe	500	445	41
Japan	100	90	8
Other	80	70	7
Total	1,222	1,080	100
Fluorocarbon type			
F-11 and F-12	1,050	930	86
Other	172	150	14

Sources: *Chemical Marketing Reporter*, *European Chemical News*, *Japan Chemical Week*, private communication with industry, and Arthur D. Little, Inc., estimates.

Table II-5. WORLD FLUOROCARBON CONSUMPTION BY END USE-1973
(units as indicated below)

End use	Amount Thousand metric tons	Amount Millions of pounds	Percent
Aerosol propellants	595	1310	55
Refrigerants	315	695	29
Foam blowing agents	75	165	7
Plastics and resins	30	65	3
Solvents	45	100	4
Other	20	45	2
Total	1080	2380	100

Source: Arthur D. Little, Inc., estimates based on private communication with industry.

Propellant applications are somewhat more important outside of the U.S., bringing the world average use in this category to 55 percent of the total. Refrigerant and foam applications are equally important in the U.S. and the rest of the world, while solvent and polymer use are slightly less important outside of the United States. In general, the U.S. accounts for roughly half of fluorocarbon demand in each use category.

C. CHLOROCARBON PRODUCTION AND USE

1. United States

a. Production - Current and historical production data for ten commercially important chlorocarbons have been collected for this study. These data are presented in Table II-6. Growth in production for some of these compounds has leveled off or dropped in the past few years. For example, trichloroethylene production reached 611 million pounds in 1970 but was only 434 million pounds in 1974--a drop of nearly 30 percent in 4 years. Ethyl chloride production increased by 25 percent between 1960 and 1965; but since the early 1960's fluctuation, rather than growth in production, has been the rule. Two rapidly growing chlorocarbons have been ethylene dichloride (EDC) and vinyl chloride monomer (VCM) for which present production levels are approximately six times as great as in 1960. This represents a growth of approximately 14 percent per annum during this period. Methyl chloride and methylene chloride have grown steadily throughout the last fifteen years to production levels more than five times greater than in 1960. This is equivalent to a growth rate of more than 12 percent per annum. Perchloroethylene and chloroform have exhibited steady but slower growth rates of approximately 10 percent annually between 1960 and 1974. Carbon tetrachloride production grew steadily through 1970 and has recently remained at a level close to 1 billion pounds per year. Figures for the production of methyl chloroform (1,1,1-trichloroethane) were not published until 1966, at which point 243 million pounds were produced. In the eight years since 1966 production has more than doubled to 590 million pounds in 1974.

Table II-6. UNITED STATES CHLOROCARBON PRODUCTION DATA (millions of pounds)

Year	Carbon Tetrachloride	Chloroform	Ethyl Chloride	Ethylene Dichloride[a]	Methyl Chloride
1960	372	76	545	1267	84
1961	384	77	497	1368	105
1962	484	98	537	1774	108
1963	519	105	592	1793	114
1964	536	119	666	2199	134
1965	594	153	686	2456	188
1966	648	179	677	3617	237
1967	714	191	618	3971	276
1968	763	181	573	4799	305
1969	883	216	679	6037	403
1970	1011	240	678	7460	423
1971	1009	231	620	7558	437
1972	997	235	576	7809	454
1973	1047	253	660	9293	544
1974	1014	301	660	7721	458

[a] Actual production of EDC is estimated to be from 1 to 15 percent greater than the reported figure.

Sources: U.S. International Trade Commission, Chemical Economics Handbook, and Arthur D. Little, Inc., estimates.

Table II-6. (continued). UNITED STATES CHLOROCARBON PRODUCTION DATA
(millions of pounds)

Year	Methyl Chloroform	Methylene Chloride	Perchloro-ethylene	Trichloro-ethylene	Vinyl Chloride
1960	NA	113	209	353	1037
1961	NA	116	225	309	1044
1962	NA	144	320	356	1312
1963	NA	148	325	368	1435
1964	NA	180	366	370	1615
1965	NA	211	429	435	2000
1966	243	267	463	480	2500
1967	NA	262	533	490	2424
1968	299	303	636	519	2969
1969	324	366	635	597	3736
1970	366	402	707	611	4040
1971	375	401	705	515	4336
1972	441	471	734	427	5089
1973	548	520	706	452	5351
1974	590	591	731	434	5700

NA = Not available or negligible.

Sources: U.S. International Trade Commission, Chemical Economics Handbook, and Arthur D. Little, Inc., estimates.

Relatively limited foreign trade data are available for the chlorocarbons (see Table II-7.). Where published, imports are small and exports vary (1974) from 4 percent of production for chloroform and perchloroethylene, to 18 percent for methylene chloride. In 1974, net exports for the 6 compounds for which data are available amounted to approximately 1 billion pounds, with an estimated favorable trade contribution in excess of $100 million.

Table II-7. UNITED STATES TRADE IN SELECTED[a] CHLOROCARBONS
(millions of pounds)

Chlorocarbon	1974	1973	1972	1971
Chloroform				
Imports	NA	NA	NA	NA
Exports	11	NA	NA	NA
Ethylene dichloride				
Imports	NA	NA	NA	NA
Exports	401	368	376	347
Methylene chloride				
Imports	12	42	11	8
Exports	106	114	104	87
Perchloroethylene				
Imports	22	45	27	44
Exports	29	80	107	NA
Trichloroethylene				
Imports	2	47	61	9
Exports	45	39	42	52
Vinyl chloride monomer				
Imports	NA	NA	NA	NA
Exports	412	421	622	620

NA = Not available or negligible.

[a] Trade data are not available for the four chlorocarbons not shown.

Source: U.S. International Trade Commission.

b. End Use - Estimated U.S. end-use patterns for the ten chlorocarbons studied are presented below.[a]

Carbon Tetrachloride - Carbon tetrachloride (CTC) is used mainly for the production of fluorocarbons. This use accounted for 95 percent of consumption in 1973. In 1968, fluorocarbon production consumed 88 percent of United States carbon tetrachloride supplies. The remaining production is believed to be mainly for export (figures are not available), grain fumigant and miscellaneous solvent applications (see Table II-8). Of the CTC consumed in the U.S., nearly all goes to the production of F-11 and F-12.

Table II-8. CARBON TETRACHLORIDE END-USE PATTERN
(percent)

End Use (1973 production 1047 million lb)	1968	1973
Fluorocarbon 12 production	57	60
Fluorocarbon 11 production	31	35
Other (including export and solvent)	12	5
Total	100	100

Source: Chemical Marketing Reporter and Arthur D. Little, Inc., estimates.

Chloroform - Chloroform in the United States is used almost totally as an intermediate in the production of fluorocarbon 22. Roughly half is used to produce F-22 gas, while approximately 40 percent is used for manufacture of fluorocarbon plastics. The third end-use category includes exports, and medical and pharmaceutical solvent applications. (see Table II-9.).

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[a] For a graphic representation of chlorocarbon uses see Figure VI-I.

Table II-9. CHLOROFORM END-USE PATTERN
(percent)

End Use (1973 production 253 million lb)	1968	1973
Fluorocarbon 22 (gas) production	60	52
Fluorocarbon 22 (for plastic) production	30	41
Other (including export and solvent)	10	7
Total	100	100

Source: Chemical Marketing Reporter and Arthur D. Little, Inc., estimates.

Ethyl Chloride - Most of the ethyl chloride produced in 1973 in the U.S. was used in the manufacture of tetraethyl lead, an antiknock compound for gasoline (see Table II-10). Miscellaneous uses include production of certain plastics, dyes, and pharmaceuticals, and use as a solvent. The end-use pattern has changed very little in the past five years. Exports are not reported separately, but are believed to be small.

Table II-10. ETHYL CHLORIDE END-USE PATTERN
(percent)

End Use (1973 production 660 million lb)	1968	1973
Tetraethyl lead production	88	85
Other (including export and solvent)	12	15
Total	100	100

Source: Chemical Marketing Reporter and Arthur D. Little, Inc., estimates.

Ethylene Dichloride - More than three-quarters of ethylene dichloride consumption in 1973 was for the manufacture of vinyl chloride monomer, a raw material for polyvinyl chloride plastic. Other applications include use as a lead scavenger in gasoline additives, and as a raw material for the production of trichloroethylene, perchloroethylene, methyl chloroform, ethylamines and vinylidene chloride (see Table II-11). Exports accounted for about 5 percent of ethylene dichloride consumption in 1973.

Table II-11. ETHYLENE DICHLORIDE END-USE PATTERN
(percent)

End Use (1973 prod. 9293 million lb)	1968	1973
Vinyl chloride production	75	78
Lead scavenger	4	3
Trichloroethylene production	3	3
Perchloroethylene production	3	3
Methyl chloroform production	2	2
Ethylamine production	3	2
Vinylidene chloride production	2	2
Other (including export)	8	8
Total	100	100

Sources: Chemical Marketing Reporter and Arthur D. Little, Inc., estimates.

Methyl Chloride - Methyl chloride is used chiefly as an intermediate in the production of silicones and tetramethyl lead (see Table II-12). Its use in producing silicones has fallen since 1968 when 60 percent of methyl chloride went to this application. Methyl chloride for production of tetramethyl lead has grown rapidly in the same 5 year period, but this application, as with tetraethyl lead, is threatened by the shift to lead-free gasoline. Miscellaneous uses include the manufacture of butyl rubber, methyl cellulose, herbicides and quaternary amines.

Table II-12. METHYL CHLORIDE END-USE PATTERN
(percent)

End Use (1973 prod. 544 million lb)	1968	1973
Silicone production	60	43
Tetramethyl lead production	18	38
Butyl rubber production	12	4
Methyl cellulose production	6	3
Herbicide production	1	2
Quaternary amine production	1	3
Other (including export)	2	7
Total	100	100

Source: Chemical Marketing Reporter and Arthur D. Little, Inc., estimates.

Methyl Chloroform (1,1,1-Trichloroethane) - Metal cleaning is the largest application for methyl chloroform, consuming approximately 70 percent of U.S. production in 1973 (see Table II-13). This chemical is employed in both cold metal cleaning and vapor degreasing. Like perchloroethylene, methyl chloroform has replaced trichloroethylene for vapor degreasing in areas where the latter has been restricted because of its link to photochemical smog formation. Although exports are not reported separately, trade publications have indicated that exports may be as high as 14 percent of production in the U.S. at present. In 1971 the use of methyl chloroform in the production of vinylidene chloride began; in 1973 this application accounted for 8 percent of U.S. production.

Table II-13. METHYL CHLOROFORM END-USE PATTERN
(percent)

End Use (1973 production 548 million lb)	1968	1973
Cleaning solvent (cold cleaning & vapor degreasing)	80	70
Exports	13	14
Vinylidene chloride production	-	8
Other (aerosols, solvent for adhesives etc.)	7	8
Total	100	100

Source: Chemical Marketing Reporter and Arthur D. Little, Inc., estimates.

Methylene Chloride - Methylene chloride is used in many applications as a solvent (see Table II -14.). Virtually none is used as a chemical intermediate. The single most important application of methylene chloride is in paint removal, which accounted for 40 percent of consumption in 1973. Exports, which were first published in 1970, represent 20 percent of consumption. Other applications are as an aerosol product vapor pressure depressant, in solvent degreasing, plastics processing, quick-drying coatings, pharmaceutical and food extraction, and as a liquid component of fire extinguishers.

Table II-14. METHYLENE CHLORIDE END-USE PATTERN
(percent)

End Use (1973 production 520 million lb)	1968	1973
Paint remover	25	40
Solvent degreasing	20	10
Aerosol sprays (solvent, vapor depressant)	10	8
Plastics processing	12	6
Other (coatings, extraction solvent)	33	16
Export	-	20
Total	100	100

Source: Chemical Marketing Reporter and Arthur D. Little, Inc., estimates.

Perchloroethylene - The largest use of perchloroethylene is in dry cleaning and textile processing, accounting for 65 percent of production in 1973 (see Table II - 15). This use has declined since 1968 due to the trend toward wash-and-wear clothing. Perchloroethylene is also used in industrial metal cleaning operations--both cold cleaning and vapor degreasing. It has largely replaced trichloroethylene for vapor degreasing in areas where air pollution regulations have restricted use of the latter. Approximately 8 percent of perchloroethylene production is used as a chemical intermediate in the production of fluorocarbons. Exports rose to about 10 percent of consumption in 1973.

Table II - 15. PERCHLOROETHYLENE END-USE PATTERN
(percent)

End Use (1973 production 706 million lb)	1968	1973
Dry cleaning solvent & textile processing	85	65
Chemical intermediate (fluorocarbons 113, 114)	8	8
Vapor degreasing	2	12
Other (including export)	5	15
Total	100	100

Source: Chemical Marketing Reporter and Arthur D. Little, Inc., estimates.

Trichloroethylene - Trichloroethylene is largely consumed in metal cleaning (see Table II -16.). This use has decreased from 94 percent in 1968 to 86 percent in 1973 due mainly to air pollution restrictions. This application includes both vapor degreasing and cold metal cleaning, of which vapor degreasing represents by far the largest share. Exports represented approximately 9 percent of production of 1973. Use of trichloroethylene as an extraction solvent has been a minor application.

Table II -16. TRICHLOROETHYLENE END-USE PATTERN
(percent)

End Use (1973 production 452 million lb)	1968	1973
Metal cleaning (cold cleaning & vapor degreasing)	94	86
Extraction solvent	3	3
Other (including export)	3	11
Total	100	100

Source: Chemical Marketing Reporter and Arthur D. Little, Inc., estimates.

Vinyl Chloride - The dominant use of vinyl chloride is in the production of polyvinyl chloride (see Table II -17). Polyvinyl chloride (PVC) is an important plastic with applications in the fields of construction, communications, transportation and packaging. In addition to its key use as an intermediate for the production of PVC, vinyl chloride is also used as an intermediate in the manufacture of methyl chloroform. Exports accounted for 8 percent of production in 1973.

Table II- 17. VINYL CHLORIDE END-USE PATTERN
(percent)

End Use (1973 prod. 5351 million lb)	1968	1973
Polyvinyl chloride (PVC) production	85	89
Export	12	8
Other	3	3
Total	100	100

Source: Chemical Marketing Reporter, and Arthur D. Little, Inc., estimates.

2. World

a. Production - United States production levels represent from 30 to 60 percent of world-wide production for the ten chlorocarbons studied (see Table II -18). Production growth rates have been somewhat greater in the rest of the world than in the United States. For example, it is estimated that chlorocarbon production (mostly of ethylene dichloride) in Japan more than doubled between 1968 and 1973.

Approximately 50 percent of world carbon tetrachloride was produced outside of the United States in 1973. Of that, 40 percent was produced in Europe and 10 percent in Japan and elsewhere. The average growth rate outside of the United States from 1968-73 was approximately 11 percent per annum and within the United States approximately 6 percent per annum during this five year period.

Approximately half of world chloroform production in 1973 was outside the United States, mainly in Europe. By way of contrast, in 1968 the United States produced approximately three-quarters of the world's chloroform.

Little information was available for world-wide production of ethyl chloride. U.S. production probably accounts for approximately half of the world total, with estimated production in Europe at about one-third of the global figure.

The United States accounted for less than half of the world's ethylene dichloride production in 1973. European production is somewhat greater than that of the United States, and Japan represents more than half of either

Table II-18. ESTIMATED WORLD CHLOROCARBON PRODUCTION - 1973
(units as indicated below)

Chlorocarbon	Regional percent of total[a] United States	Europe	Other	World total Thousand metric tons	Millions of pounds
Carbon tetrachloride	50	40	10	950	2,100
Chloroform	50	40	10	225	500
Ethyl chloride	55	30	15	550	1,200
Ethylene dichloride	35	40	25	12,000	26,450
Methyl chloride	60	35	5	400	875
Methyl chloroform	60	30	10	420	925
Methylene chloride	55	30	15	425	925
Pechloroethylene	45	45	10	750	1,650
Trichloroethylene	30	55	15	700	1,550
Vinyl chloride	35	40	25	7,100	15,650

[a] Rounded to nearest 5 percent.

Source: U.S. and foreign trade publications and Arthur D. Little, Inc., estimates.

Europe or the United States. Total world production in 1973 was approximately 12 million metric tons.

Almost all methyl chloride is produced in Europe and the United States. The United States accounted for approximately 60 percent of world production in 1973 and Europe about 35 percent. The world production figure was about 400 thousand metric tons.

Methyl chloroform, or 1,1,1 - trichloroethane, follows a similar pattern to the other chlorocarbons in terms of world production allotment among regions. Of the 375 thousand metric tons produced in 1973, the U.S. accounted for 60 percent, Europe for 30 percent and the rest of the world for 10 percent.

More than half of the world's methylene chloride is produced in the United States. Europe produced 30 percent in 1973 and Japan 15 percent. Outside of the United States methylene chloride production rose 42 percent between 1968-1973; within the United States it grew 72 percent or nearly 12 percent per year.

More than half (55 percent) of world perchloroethylene production is outside the United States, mainly in Europe. Japan accounts for 10 percent of world production. The world growth rate between 1968-1973 was 36 percent, or 6 percent per year.

Two-thirds of the world's trichloroethylene is produced outside of the United States. Europe accounts for just over half the world production of trichloroethylene. Japan produces 15 percent of the world supply. The growth rate of trichloroethylene has been very low: from 1968 to 1973 production rose only 9 percent, or 2 percent per year. U.S. production fell in this time period due, in part, to air pollution restrictions.

As with ethylene dichloride, world vinyl chloride production is slightly greater in Europe than in the United States. Japan produces approximately 25 percent of the world total, which was approximately seven million metric tons in 1973.

b. End Use - Only limited information is available on world application patterns outside of the United States. However, the available data for both Europe and Japan indicate that end-use patterns for these compounds are very similar throughout the world. A notable exception is the use of trichloroethylene for metal cleaning in Europe. This application has become relatively less important in the United States because of photochemical smog problems.

III. HALOCARBON EMISSIONS TO THE ATMOSPHERE

A. INTRODUCTION

Just as the United States accounts for approximately half of world production for the compounds of interest, so too does the United States account for this fraction of world halocarbon emissions. This chapter examines the various emission sources to determine the magnitude of emissions in each application and thus lays the groundwork for Chapter IV.

The predominant chlorofluorocarbon emission source, both in the United States and worldwide, is the chlorofluorocarbon-filled aerosol can. These chemicals are found in only about half of all aerosol products, with greatest use being in personal products such as anti-perspirants and hair sprays. The second greatest source of chlorofluorocarbon emissions is automotive and commercial air-conditioning equipment. The combined atmospheric emissions from all propellant and refrigerant applications accounted for almost 90 percent of all U.S. chlorofluorocarbon emissions (about 725 million pounds) in 1973.

Among the chlorocarbons, the greatest atmospheric emissions are from those chemicals commonly used as solvents. Methyl chloroform, methylene chloride, perchloroethylene and trichloroethylene all had 1973 emission levels in the U.S. estimated at greater than 400 million pounds.

B. DISCUSSION OF EMISSION ESTIMATES AND ENVIRONMENTAL FATE

1. Atmospheric Emissions from Chemical Manufacturing Processes, Transportation and Storage

Emissions of a particular hydrocarbon (or halocarbon) from chemical manufacturing can ge associated with three different processes:

- The process(es) used in the initial manufacture of the chemical,
- The process(es) used to manufacture other chemicals from the particular chemical; i.e., its use as an intermediate, and
- Processes in which the particular chemical may be produced as a by-product.

Emissions related to the third category above, i.e., by-product formation, are not being considered in this study even though the amounts may be significant.[a] Emissions of a particular chemical related to the first and second categories are generally on the same order of magnitude, on the basis of pounds lost per pound of product produced.

Two recent surveys, for the EPA, of hydrocarbon emissions from chemical manufacturing processes indicate that, on the average, total hydrocarbon emissions are between 0.01 and 0.02 pounds per pound of product produced. Details are given in Tables III-1 and III-2.

The emission factors given in Tables III-1 and III-2 allow the estimation of an average emission factor to be used for the specific chemicals in this study. It should be noted that, while the type of reactions reported on in Table III-2 are more pertinent to this study (because they deal only with

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a. This emission category is relatively unimportant for those chemicals which have large use-related emissions, such as the chlorinated solvents.

Table III-1. HYDROCARBON EMISSIONS[a] FROM CHEMICAL MANUFACTURE

Reaction	Total hydrocarbon emissions 1973 (million lbs/yr)	Production 1973 (million lbs/yr)	Hydrocarbon Loss rate (lbs/lbs product produced)
I) 40 Industrially important organic chemical reactions	1227.6	95,400[d]	.0129
II) SPECIFIC EXAMPLES:			
1. Vinyl chloride production	17.6	5,300	.0033
2. Ethylene dichloride (EDC) production:			
a. via oxychlorination	95.1[b]	~4,180	.0227[b]
b. via direct chlorination	29.0[c]	~5,110	.0057[c]

[a] Excludes methane; includes H_2S and all volatile organics.

[b] Loss of EDC itself from this manufacturing process is estimated to be 81.4 million lbs/yr resulting in a loss rate of .0195 lb/lb of EDC produced.

[c] Loss of EDC itself from this manufacturing process is estimated to be 16.8 million lbs/yr or a loss rate of .0033 lbs/lb of EDC produced.

[d] Actual production in 1973 estimated to be 90 percent of production capacity (ADL estimate).

Sources:

1. "Survey Reports on Atmospheric Emissions from the Petrochemical Industry" (in 4 volumes); U.S. Environmental Protection Agency, 1974. Report numbers: EPA-450/3-73-005a-d.

2. "Engineering and Cost Study of Air Pollution Control for the Petrochemical Industry, Volume 3: Ethylene Dichloride Manufacture by Oxychlorination," U.S. Environmental Protection Agency, November 1974. Report Number: EPA-450/3-73-006c.

Table III-2. HYDROCARBON EMISSIONS[a] FROM CHEMICAL MANUFACTURING PROCESSES INVOLVING CHLORINATION

	Estimated total hydrocarbon emissions-1970: aver. per process (lbs/lb of product)	Estimated loss of manufactured chemical-1970: aver. per process (lbs/lb of product)
I) From 25 industrially important chlorination reactions	.016 ± .009	- - -
II)[b] From 16 industrially important chlorination reactions for the manufacture of ethylene dichloride, carbon tetrachloride, ethyl chloride, methyl chloroform, chloroform, methyl chloride, methylene chloride, tetrachloroethylene, and trichloroethylene.	.019 ± .009	.008 ± .008

[a] The estimated emissions given were based on little or no real data on actual emissions; the error limits given in the table are average deviations.

[b] The reactions here included in the 25 reactions of I.

Source:

"Air Pollution from Chlorination Process;" Report prepared for Office of Air Programs, U.S. Environmental Protection Agency, March, 1972, by Process Research, Inc., Industrial Planning and Research, Cincinnati, Ohio under Task Order Number 23 of Contract Number CPA 70-1.

chlorinated hydrocarbon production) than those reported on in Table III-1, the accuracy of the emissions estimates in Table III-1 are considered to be much more reliable. Data for the emissions estimates in Table III-1 were obtained from detailed questionnaires mailed out to the manufacturing companies while essentially no real emissions data were used for the results shown in Table III-2.

In light of these data, it seems reasonable to state that average total hydrocarbon emissions from a manufacturing process is 0.013 pounds per pound of product produced, and that a reasonable average for losses of the particular compounds of interest is 0.006[a] pounds per pound of product produced.

A more precise estimate for losses of EDC from EDC manufacturing processes is possible from the information given in Table III-1. Assuming that, in 1973, 45% of EDC production was via oxychlorination and 55% via direct chlorination, a weighted EDC loss rate of 0.013 pounds per pound of product is obtained.

Since it is desirable to have one loss estimate that covers both (1) the manufacturing process, and (2) the transportation and storage of the particular chemical, a transportation and storage loss must be estimated. For those chemicals used only as intermediates, transportation will be in bulk via rail, truck, ship, or barge (or via pipeline for intraplant transfers). These modes of transport should entail relatively small losses, estimated to be on the order of about 0.001[a] pounds per pound of product.

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[a] These average emission rates are believed to be conservative estimates.

Storage will also be in bulk and should not add measurably to this loss factor.

This estimated transportation and storage loss factor, when added to the manufacturing process loss factor estimated above for a particular chemical, results in an estimated loss factor covering both manufacture, transportation and storage of 0.007 pounds per pound of product. The total loss rate of EDC should be kept at 0.013 pounds per pound of product since most EDC is consumed at the site of its manufacture for vinyl chloride production.

2. Environmental Fate of Fluorocarbons and Chlorocarbons

This section briefly describes the anticipated environmental fate of the fluorocarbons and chlorocarbons under study in an attempt to predict which of them should warrant the most concern.

Most all of the compounds of interest have low boiling points (therefore, high vapor pressures), and low solubility in water (see Table III-3). These two facts help insure that almost all losses of these chemicals (i.e., from production, transportation, storage, use, and disposal) find their way, eventually, into the atmosphere. It is estimated that approximately 1 percent of the losses of these chemicals fails to reach the atmosphere; larger amounts of some of these chemicals are initially discharged in waste waters, and some of this dissolved portion will be "lost" by hydrolysis or absorption, but the major portion will be returned to the atmosphere in short order. For example, the mean residence time of perchloroethylene in the ocean has been estimated as 1 month.[a]

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[a] Assessing Potential Ocean Pollutants, National Academy of Sciences, Washington, D.C., 1975.

Table III-3. SOME PROPERTIES OF FLUOROCARBONS AND CHLOROCARBONS

Chemical	Formula	BP(°C)	Solubility (wt percent) in water (25°C)
F-11	CCl_3F	23.82	0.011
F-12	CCl_2F_2	-29.79	0.028
F-13	$CClF_3$	-80.00	0.009
F-14	CF_4	-128.00	0.0015
F-21	$CHCl_2F$	8.9	0.95
F-22	$CHClF_2$	-40.75	0.13
F-113	$CCl_2F\text{-}CClF_2$	47.57	0.017
F-114	$CClF_2\text{-}CClF_2$	3.77	0.013
F-115	$CClF_2\text{-}CF_3$	-39.10	0.006
F-116	$CF_3\text{-}CF_3$	-78.20	N/A
F-13B1	$CBrF_3$	-57.75	0.0095 (70°F)
F-114B2	$CBrF_2\text{-}CBrF_2$	47.3	N/A
F-C-318	$\underbrace{CF_2CF_2CF_2C}F_2$	5.8	N/A
F-502 (azeotrope)	$CHClF_2$ (48.8%) $CClF_2CF_3$ (51.2%)	-45.42	N/A
Carbon tetrachloride	CCl_4	76.80	0.08 (20°C)
Chloroform	$CHCl_3$	61.26	1.0 (15°C)
Ethyl chloride	CH_3CH_2Cl	12.20	0.574g/100ml (20°)
Ethylene dichloride	CH_2ClCH_2Cl	83.50	0.869g/100ml (20°)
Methyl chloride	CH_3Cl	-24.22	$400cm^3/100ml$
Methyl chloroform	CCl_3CH_3	74.10	slightly soluble
Methylene chloride	CH_2Cl_2	40.10	2g/100ml (20°C)
Perchlorethylene	$CCl_2=CCl_2$	121.02	slightly soluble
Trichloroethylene	$CHCl=CCl_2$	87.00	0.1
Vinyl chloride	CH_2CHCl	-13.90	slightly soluble

Sources: DuPont Technical Literature, and Handbook of Chemistry and Physics, 44th Edition, CR Publishing Co., Cleveland, Ohio.

The next most important aspect of the chemicals being investigated is their degree of chemical stability and inertness. The carbon-fluorine bond is a strong one in comparison with carbon bonds to chlorine, bromine, hydrogen or a second carbon atom. Additionally, increasing the number of fluorine atoms in the molecule tends to increase the carbon-chlorine bond strength on the molecule. The resistance to degradation by hydrolysis and heat is said to parallel bond energies and thus the fluorocarbons are considered to be quite stable and inert. Within the group of fluorocarbons, the perfluoro compounds (e.g., CF_4, C_2F_6) would be expected to be the most stable, followed by the chlorofluorocarbons (e.g., CCl_3F, CCl_2F_2) and, finally, the chlorofluorohydrocarbons (e.g., $CHClF_2$). Below the fluorocarbons in stability and inertness would be the chlorocarbons (chlorohydrocarbons)--with one or more exceptions. The one fairly certain exception is carbon tetrachloride which is more akin to the fluorocarbons in its relative stability and inertness.

The general rule that seems to follow from the above is that the most stable and inert compounds are those that are the most highly halogenated (i.e., have the least number of hydrogen atoms), and that, of all the halogenated compounds, the fluorinated compounds are the most stable. The presence of a double bond (e.g., in $CCl_2=CCl_2$ and $CHCl=CCl_2$), a hydrogen atom, or a small ring structure (e.g., in F-C318) tends to decrease the stability of the compound. A summary listing of the chemicals being studied is given in Table III-4, broken down into three groups based on their expected degree of stability. This degree of stability, along with estimated

Table III-4. RELATIVE STABILITY OF THE HALOCARBONS[a]

Group I: Relatively high stability (over ten-year atmospheric residence)

F-11
F-12
*F-13
*F-14
F-113
F-114

*F-115
*F-116
*F-13B1
*F-114B2
*F-C318
carbon tetrachloride

Group II: Intermediate stability (under ten-year atmospheric residence)

F-22
*F-21

methyl chloroform

Group III: Relatively low stability (under one-year atmospheric residence)

chloroform
ethyl chloride
methyl chloride
vinyl chloride

ethylene dichloride
perchloroethylene
methylene chloride
trichloroethylene

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a. The five halocarbons that were emphasized in the analysis of likely economic impact are underlined. These chemicals are of relatively high stability and are produced in large quantities relative to the other halocarbons in Groups I and II. F-502 contains F-22 and F-115 and is not shown separately. The compounds marked with an asterisk (*) are produced only in relatively small quantities.

Source: Arthur D. Little, Inc., estimates, based on private communication with EPA, and Wofsy, *et al.*, *Science*, **187**, 535 (Feb. 14, 1975).

levels of atmospheric emission, determined the emphasis of our analysis in the following chapters of the report.

It is generally agreed that any chemical with a high vapor pressure at ambient temperatures, a low solubility in water, and high chemical stability and inertness will, in large measure, accumulate and persist in the atmosphere. The main uncertainties today are over the degree of accumulation, the duration of the persistence, and the nature of possible reactions with ozone and other components of the atmosphere. Additionally, the time required for these chemicals to reach the stratosphere (where the ozone is found) is an important parameter.

With respect to accumulation of fluorocarbons, specifically of F-11, it has been contended[a] that measured atmospheric concentration levels, when summed together on a global scale, equal the net world production of F-11 up to the time the measurements were made. The variability of the measurements on which this estimate is based is large enough, however, to cast some doubt on the implication that there is no loss of fluorocarbons (due to degradation or chemical reaction) in the lower atmosphere.

It is also contended[a] that fluorocarbons have a residence time in the atmosphere of between 40 and 150 years. Carbon tetrachloride should be classed with the fluorocarbons in this respect as its lifetime has been estimated to be 30 to 50 years. Incorporated within these residence times is a delay period of several months[a] required for these chemicals to go from ground level up to the stratosphere (roughly ranging from 50,000 to 165,000 feet). It is only within the stratosphere, more specifically around 50,000 to 115,000 feet, that some scientists believe fluorocarbon-ozone reactions are likely to occur, with a net loss of ozone.[b]

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[a] Hearings before the Subcommittee on Public Health and Environment of the Committee on Interstate and Foreign Commerce, U.S. House of Representatives, 93rd Congress, 2nd Session, on H.R. 17577 and H.R. 17545, December 11 and 12, 1974 (Serial No. 93-110), p. 428.

In marked contrast to the fluorocarbons (including carbon tetrachloride) the other chlorocarbons under study in this work are not expected to have such long lifetimes in the atmosphere. Fluorocarbons 21, 22, and others containing hydrogen atoms may also fall into this group because all of these chemicals contain a bond that is relatively susceptible to attack by hydroxyl (OH) radicals in the lower atmosphere. These bonds are the carbon-carbon double bonds and the carbon-hydrogen bonds.

C. FLUOROCARBON EMISSIONS TO THE ATMOSPHERE

1. United States

a. Production, Transport and Storage - Emissions of fluorocarbons to the atmosphere in production, transport and storage are small (ca. 1 percent of total emissions). These chemicals have a high unit value relative to many other industrial organic chemicals produced in commercial quantities and there is, therefore, a strong economic incentive for close control of loss during production, transport and storage. Furthermore, transport and storage are usually in bulk quantities and in sealed metal containers. Small losses may occur in transfer and flushing operations, but these are negligible compared to losses in end use and disposal (see Table III-5).

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[a] EPA estimate.

[b] The reaction mechanism proposed involves first the production of halogen atoms following absorption of ultraviolet light by the halocarbon. The halogen atom is then involved in a catalytic reaction with ozone, the net result of which is the conversion of ozone (O_3) to oxygen (O_2).

b. End Use and Disposal - As indicated in Table III-5, the major U.S. atmospheric emissions of fluorocarbons are from propellant and refrigerant applications. Propellant losses account for an estimated 62 percent of total emissions, while refrigerant emissions comprise an additional 26 percent of the total. Emissions from foam blowing and solvent applications are estimated to be 5 percent and 6 percent, respectively. Emissions from manufacture of fluorocarbon resins are negligible.

Also shown in Table III-5 are U.S. fluorocarbon emissions by fluorocarbon type. Fluorocarbon 12 accounted for approximately 390 million pounds (48 percent) of the total estimated emissions of 824 million pounds in 1973. Fluorocarbon 11 represented 34 percent of total emissions, while F-22 and other fluorocarbons accounted for 7 and 11 percent of 1973 losses, respectively. The bases for these emission estimates are detailed in Chapter IV.

2. World

a. Production, Transport and Storage - As is the case with this category of emissions in the United States, world atmospheric emissions of fluorocarbons from production, transport and storage are judged to be on the order of 1 percent of total production, or 11 thousand metric tons in 1973. (World production in 1973 was estimated in Table II-4 to have been approximately 1.1 million metric tons.)

Table III-5. ESTIMATED U.S. FLUOROCARBON EMISSIONS-1973
(millions of pounds)

Fluorocarbon	Production transport and storage emissions		Annual emissions from use and disposal						
	Production (million lbs)	Emissions[a] (1 percent)	Propellant	Refrigerant	Solvent	Blowing agent	Plastic resin	Total[b]	Percent of total
F-11	334	3.3	236.9	11	sm.	29.3	-	280.5	34.0
F-12	489	4.9	249.4	130.5	-	7.5	-	392.3	47.6
F-22	136	1.4	sm.	59.5	-	-	sm.	60.9	7.4
F-113	59	0.6	-	11	50	3.7	sm.	90.4	11.0
F-114	26	0.3	24.7		-		sm.		
Other	12	0.1	sm.		-		-		
Total[b]	1056	10.6	511.0	212.0	50	40.5	sm.	824.1	—
Percent of total	—	1.3	62.0	25.7	6.1	4.9	—	—	100.0

'sm.' = less than 5 million pounds; '-' = none or negligible.

[a] Emissions from production transport and storage are judged to be approximately 1 percent of total production.

[b] Does not include 'sm.'

Source: Arthur D. Little, Inc., estimates, based on industry contacts.

b. End-Use and Disposal - The world pattern for atmospheric emissions of the fluorocarbons parallels that of the United States in terms of emission source. The greatest emissions are from propellant and refrigerant applications; other emission sources are small by comparison.

Estimated world emissions of fluorocarbons as aerosol propellant are presented in Table III-6. Total 1973 emissions are estimated to be 488 thousand metric tons (1,076 million pounds). The U.S. accounted for nearly half of these emissions and Europe accounted for an additional third of the total.

Estimated world emissions of fluorocarbon refrigerants are presented in Table III-7. Total 1973 emissions are estimated at 207 thousand metric tons (457 million pounds). As in the case of propellants, the U.S. accounted for the largest part (47 percent) of the emissions, and Europe (39 percent) was the second largest regional emission source.

Finally, estimated 1973 world emissions of fluorocarbons from use as solvents and foam blowing agents are 90 thousand metric tons (198 million pounds), with the U.S. accounting for 46 percent of total emissions in this category.

Total 1973 world fluorocarbon emissions are therefore believed to be on the order of 785 thousand metric tons:

- propellant emissions - 488 thousand metric tons
- refrigerant emissions - 207 thousand metric tons
- other use emissions - 90 thousand metric tons

Total 785 thousand metric tons

Table III-6. WORLD EMISSIONS OF FLUOROCARBON AEROSOL PROPELLANTS - 1973

(units as indicated below)

Region	Estimated emissions		Percent of total
	(thousand metric tons)	(millions of pounds)	
United States	232	511	48
Europe	170	375	34
Other	86	190	18
Total	488	1076	100

Source: Arthur D. Little, Inc., estimates.

Table III-7. WORLD EMISSIONS OF FLUOROCARBON REFRIGERANTS - 1973

(units as indicated below)

Region	Estimated emissions		Percent of total
	(thousand metric tons)	(millions of pounds)	
United States	96	212	47
Europe	81	179	39
Other	30	66	14
Total	207	457	100

Source: Arthur D. Little, Inc., estimates.

D. CHLOROCARBON EMISSIONS TO THE ATMOSPHERE

1. United States

a. Production, Transport and Storage - Emissions to the atmosphere of chlorocarbons during manufacture, transport and storage are judged to be on the order of 0.5 to 1.5 percent of production. For the chemicals used only as intermediates, losses during transport and storage are minimal since they are usually transported in bulk form over short distances and are stored for relatively short periods in closed vessels. Ethylene dichloride emissions are far greater than any of the other chlorocarbons simply because of the massive amount manufactured. Trichloroethylene, perchloroethylene, methyl chloroform and methylene chloride are believed to have emission rates of one percent during production, transport and storage. Ethyl chloride and methyl chloride are judged to have emission rates of 0.7 percent each, while carbon tetrochloride and chloroform losses during production transport and storage are on the order of 1.5 percent of production. These emissions, as well as those from end-use and disposal are discussed below and are summarized in Table III-18.

b. End-Use and Disposal - There is tremendous variation among the chlorocarbons in emissions to the atmosphere from end-use. For those chemicals that are used as chemical intermediates, the emissions are small. For example, chloroform and carbon tetrachloride emissions are believed to be no greater than one percent in the manufacture of fluorocarbons. On the other hand, for chlorocarbons used in dry cleaning and metal cleaning, it is likely that nearly all of the product going to these applications eventually is lost to the atmosphere. Emission estimates for the 10 chlorocarbons studied are developed below.

In the tables below "Percent" refers to estimated emissions from production transport and storage (as a percent of production, P), emissions from use as a chemical intermediate (as a percent of consumption in this application, C), emissions from end uses (as a percent of production, P), and a correction for emissions not reaching the atmosphere calculated as a percent of total emissions, E)[a]; therefore the percent column does not total to 100.

Using the carbon tetrachloride production figure for 1973 of 1047 million pounds, approximately 1.5 percent (15.7 million pounds) of this chemical product is lost to the atmosphere during production, transport and storage. Together with the losses from solvent use and use as a chemical intermediate, an estimated 46 million pounds of carbon tetrachloride was lost to the atmosphere in 1973 in the United States (see Table III-8).

Table III-8. ESTIMATED U.S. CARBON TETRACHLORIDE EMISSIONS-1973

Emission Source	Percent	Basis[b]	Amount (million pounds)
Production, transport and storage	1.5	P	15.7
Chemical intermediate: fluorocarbons 11 & 12	1.0	C	9.9
Other (including solvent)	2.0	P	20.9
Rebased to environment but not reaching atmosphere (due to hydrolysis or water dissolution)	-1.0	E	-0.5
Total	-	-	46.0

Source: Arthur D. Little, Inc., estimates.

[a] See Section B. 2. (p. III-7) of this chapter for derivation.

[b] See explaination of "Basis" in text, above.

U.S. atmospheric emissions of chloroform in 1973 are estimated to be on the order of 14 million pounds. The loss rate during production, transport and storage is judged to be the same as for carbon tetrachloride: 1.5 percent of production. In its use as a chemical intermediate for the production of F-22, it is estimated that a 1 percent loss rate is appropriate for the amount of chloroform going to this application (ca. 235 million pounds, based on Table II-9). Emissions resulting from solvent applications are estimated at 3 percent of total production.

Table III-9. ESTIMATED U.S. CHLOROFORM EMISSIONS-1973

Emission source	Percent	Basis	Amount (million pounds)
Production, transport and storage	1.5	P	3.8
Chemical intermediate: fluorocarbon 22	1.0	C	2.4
Other (including solvent)	3.0	P	7.6
Released to environment but not reaching atmosphere (due to hydrolysis or water dissolution)	-1.0	E	-0.1
Total	—	—	13.7

Source: Arthur D. Little, Inc., estimates.

In 1974, 85 percent of the ethyl chloride produced in the United States was consumed in the manufacture of tetraethyl lead. Using an emission rate of 0.6 percent for this process, 3.4 million pounds were lost to the atmosphere in 1973. The emission rate for the "Other" category is higher than this because it includes use as a solvent. From the total potential emissions of 17.9 million pounds we have subtracted 1 percent of the losses (0.2 million pounds) from the total to take into account the amount that is likely to have been hydrolyzed. The total U.S. amount of ethyl chloride lost to the atmosphere in 1973 is estimated at 17.7 million pounds (see Table III-10).

Table III-10. ESTIMATED U.S. ETHYL CHLORIDE EMISSIONS-1973

Emission source	Percent	Basis	Amount (million pounds)
Production, transport and storage	0.7	P	4.6
Chemical intermediate: tetraethyl lead	0.6	C	3.4
Other (including export)	1.5	P	9.9
Released to environment but not reaching atmosphere (due to hydrolysis or water dissolution)	-1.0	E	-0.2
Total	–	–	17.7

Source: Arthur D. Little, Inc., estimates.

As was developed in the previous chapter, the estimated loss rate for ethylene dichloride (EDC) production, transport and storage is 1.3 percent of production. The estimated loss rates for all of the end uses of ethylene dichloride are small with the exception of the "Other" category which includes uses for EDC in this category (8 percent of total EDC demand) is the most critical determinant of EDC emissions. Total U.S. emissions of EDC were on the order of 440 million pounds in 1973 (see Table III-11).

Table III-11. ESTIMATED U.S. ETHYLENE DICHLORIDE EMISSIONS-1973

Emission source	Percent	Basis	Amount (million pounds)
Production, transport and storage	1.3	P	120.8
Chemical intermediate:			
vinyl chloride	0.2	C	14.5
lead scavenger	0.1	C	2.8
trichloroethylene	0.6	C	1.7
perchloroethylene	0.6	C	1.7
methyl chloroform	0.6	C	0.9
ethylamines	0.6	C	1.1
vinylidene chloride	0.6	C	1.1
Other (including export)	40.0	C	297.4
Released to environment but not reaching atmosphere (due to hydrolysis or water dissolution)	-1.0	E	-4.4
Total	—		437.6

Source: Arthur D. Little, Inc., estimates.

Methyl chloride is used almost exclusively as an intermediate to produce other chemicals and thus emissions are minimal. More than 80 percent of methyl chloride was consumed in the production of silicones and tetramethyl lead in 1973. The "Other" category emission rate is higher than that for chemical intermediates because some of these miscellaneous uses have relatively high potential for loss of the chemical to the atmsophere. Total 1973 U.S. emissions are estimated to have been 10.5 million pounds (see Table III-12).

Table III-12. ESTIMATED U.S. METHYL CHLORIDE EMISSIONS-1973

Emission source	Percent	Basis	Amount (million pounds)
Production, transport and storage	0.7	P	3.8
Chemical intermediate:			
silicones	0.6	C	1.4
tetramethyl lead	0.6	C	1.2
butyl rubber	0.6	C	0.1
methyl cellulose	0.6	C	0.1
herbicides	0.6	C	0.1
quaternary amines	0.6	C	0.1
Other	10.0	C	3.8
Released to environment but not reaching atmosphere (due to hydrolysis or water dissolution)	-1.0	E	-0.1
Total	—	—	10.5

Source: Arthur D. Little, Inc., estimates.

Virtually all of the methyl chloroform used in metal degreasing (cleaning solvent) and as a solvent for adhesives or other materials evaporates and is thus released to the atmosphere. Atmospheric emission from the production of methyl chloroform and from its use as an intermediate to produce vinylidene chloride are small by comparison. An estimated 428.9 million pounds of methyl chloroform was released to the atmosphere in 1973 in the U.S. (see Table III-13).

Table III-13. ESTIMATED U.S. METHYL CHLOROFORM EMISSIONS-1973

Emission source	Percent	Basis	Amount (million pounds)
Production, transport and storage	1.0	P	5.5
Chemical intermediate: vinylidene chloride	0.6	C	0.3
End Uses:			
cleaning solvent	70.0	P	383.6
other (including adhesive solvent)	8.0	P	43.8
Released to environment but not reaching atmosphere (due to hydrolysis or water dissolution)	-1.0	E	-4.3
Total	-	-	428.9

Source: Arthur D. Little, Inc., estimates.

As in the case of methyl chloroform, the majority of the end uses of methylene chloride result in loss to the atmosphere by evaporation. The large "paint remover and other" category includes plastics processing, and these two uses account for over 75 percent of methylene chloride emissions. The other important emission sources are use of methylene chloride in solvent degreasing and in aerosol applications, where the chemical acts as both vapor depressant and solvent. In all, it is estimated that about 430 million pounds of methylene chloride went into the atmosphere from the U.S. in 1973 (see Table III-14).

Table III-14. ESTIMATED U.S. METHYLENE CHLORIDE EMISSIONS-1973

Emission source	Percent	Basis	Amount (million pounds)
Production, transport and storage	1.0	P	5.2
End uses:			
cleaning solvent	10.0	P	52.0
aerosols	8.0	P	42.0
paint remover	65.0	P	338.0
Released to the environment but not reaching atmosphere (due to hydrolysis or water dissolution)	-1.0	E	-4.4
Total	-	-	432.8

Source: Arthur D. Little, Inc., estimates.

The major source of U.S. perchloroethylene atmospheric emissions is the use of this chemical as a dry cleaning and textile processing solvent. This application accounted for about 460 million pounds (77 percent) of the estimated U.S. 1973 emissions of about 600 million pounds. Emissions from other end uses were small by comparison, as were emissions from production, transport and storage (see Table III-15).

Table III-15. ESTIMATED U.S. PERCHLOROETHYLENE EMISSIONS-1973

Emission source	Percent	Basis	Amount (million pounds)
Production, transport and storage	1.0	P	7.1
Chemical intermediate: fluorocarbons 113 & 114	1.0	C	0.6
End uses:			
dry cleaning and textile processing	65.0	P	458.9
cleaning solvent	12.0	P	84.7
other (including export)	50.0	C	53.0
Released to the environment but not reaching atmosphere (due to hydrolysis or water dissolution)	-1.0	E	-6.0
Total	-	-	598.3

Source: Arthur D. Little, Inc., estimates.

In its end uses as a metal cleaning and extraction solvent, it is assumed that nearly all of the trichloroethylene going to these uses represents emissions to the atmosphere in that year. These two applications accounted for about 390 million pounds (90 percent) of the nearly 430 million pounds of trichloroethylene estimated to have been released to the atmosphere from the U.S. in 1973. This emission level represented about 95 percent of 1973 U.S. production of trichloroethylene (see Table III-16).

Table III-16. ESTIMATED U.S. TRICHLOROETHYLENE EMISSIONS-1973

Emission source	Percent	Basis	Amount (million pounds)
Production, transport and storage	1.0	P	4.5
End uses:			
cleaning solvent	86.0	P	388.7
extraction solvent	3.0	P	13.6
Other (including export)	50.0	C	24.9
Released to the environment but not reaching atmosphere (due to hydrolysis or water dissolution)	-1.0	E	-4.3
Total	-	-	427.4

Source: Arthur D. Littl^, Inc., estimates.

Vinyl chloride monomer (VCM) emissions approached 200 million pounds in 1973, or about 3.7 percent of total production of the compound (see Table III-17). The loss of VCM during polymerization was approximately 184 million pounds, or 93 percent of total emissions.

Table III-17. ESTIMATED U.S. VINYL CHLORIDE MONOMER EMISSIONS-1973

Emission source	Percent	Basis	Amount (million pounds)
Production, transport and storage	0.3	P	14.5
Chemical intermediate: polyvinyl chloride	3.9	C	184.1
Released to the environment but not reaching atmosphere (due to hydrolysis or water dissolution)	-1.0	E	-2.0
Total	-	-	196.6

Source: Arthur D. Little, Inc., and EPA estimates.

Table III-18. ESTIMATED U.S. CHLOROCARBON EMISSIONS-1973
(millions of pounds)

Chlorocarbon	Emissions from production transport and storage	Emissions from end use and disposal	Total potential emissions	Total adjusted[a] emissions
Carbon tetrachloride	15.7	30.8	46.5	46.0
Chloroform	3.8	10.0	13.8	13.7
Ethyl chloride	4.6	13.3	17.9	17.7
Ethylene dichloride	120.8	321.2	442.0	437.6
Methyl chloride	3.8	6.8	10.6	10.5
Methyl chloroform	5.5	427.7	433.2	428.9
Methylene chloride	5.2	432.0	437.2	432.8
Perchloroethylene	7.1	597.2	604.3	598.3
Trichloroethylene	4.5	427.2	431.7	427.4
Vinyl chloride[b]	14.5	184.1	198.6	196.6

[a] The amount of chlorocarbon released to the environment but probably not reaching the atmosphere due to hydrolysis or water dissolution has been subtracted in this column.

[b] EPA estimates.

Source: Athur D. Little, Inc., estimates.

2. World

a. Production, Transport and Storage - World atmospheric emissions of the chlorocarbons from production, transport and storage are believed to be on the same order of magnitude, percentagewise, as in the United States. They range from about 30 percent of total emissions for carbon tetrachloride and chloroform to approximately one percent of total emissions for methyl chloroform and trichloroethylene. Again, it is the end-use pattern that is the key variable in determining which of the chlorocarbons will have relatively large (greater than 100 thousand metric ton) atmosphere emissions.

b. End-Use and Disposal - For all of the chlorocarbons, application emissions are judged to be greater than disposal emissions. These categories have been combined because the disposal losses tend to be small and not easily quantifiable and also because the distinction between 'end use' and disposal is not always well-defined. As stated above, the major emissions (for those chemicals with large emissions) occur in the end use category.

The world emission estimates shown in Table III-19 combine the total production, transport, storage, end use and disposal estimates into one figure for each chlorocarbon. The purpose of this world estimate is to give an indication of the importance of various geographic emission sources in relation to the U.S. emissions, and also to indicate the approximate level of total chlorocarbon emissions to the atmosphere on a global basis. As discussed previously, most of these chemicals are believed by atmospheric scientists to be subject to high rates of decomposition in the lower atmosphere.

Table III-19. ESTIMATED WORLD CHLOROCARBON EMISSIONS-1973
(units as indicated below)

Chlorocarbon	Regional percent of total[a]			World total	
	United States	Europe	Other	Thousand metric tons	Millions of pounds
Carbon tetrachloride	50	40	10	41.7	92.0
Chloroform	50	40	10	12.4	27.4
Ethyl chloride	55	30	15	14.6	32.2
Ethylene dichloride	35	40	25	565.2	1,246.3
Methyl chloride	60	35	5	7.9	17.5
Methyl chloroform	60	30	10	324.2	714.8
Methylene chloride	55	30	15	346.4	763.8
Perchloroethylene	45	45	10	609.0	1,342.9
Trichloroethylene	30	55	15	648.3	1,429.6
Vinyl chloride[b]	25	40	35	351.6	775.3

[a] Rounded to nearest 5 percent.

[b] EPA estimates.

Source: Arthur D. Little, Inc., estimates.

IV. ANALYSIS OF MAJOR U.S. EMISSION SOURCES AND ALTERNATIVES FOR EMISSION ABATEMENT

A. INTRODUCTION

The preceding chapter identified the major sources of halocarbon emissions. The high-volume applications of these compounds (aerosols, refrigeration, plastic foam production, and solvent cleaning) are the most sensitive points for emission reduction strategies. This chapter discusses in detail the technologies of these major applications and sets forth the most feasible emission control options.

B. PRODUCTION, TRANSPORT, AND STORAGE EMISSIONS

Atmsopheric emissions of the chlorocarbons and fluorocarbons from production, transport and disposal are extremely small (ca. 1 percent of total emissions) for those compounds having relatively large atmospheric discharges. In view of the small size of these emissions relative to those from end use and disposal and the relative cost/effectiveness of reducing emissions from these two groupings, we have not examined the alternatives for emission abatement from production, transport, and storage.

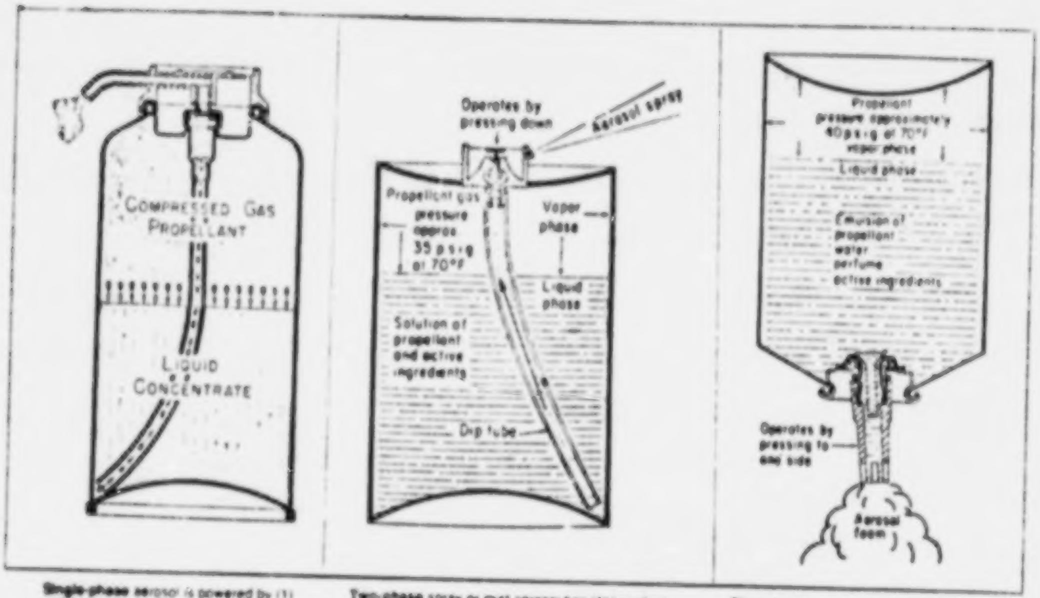
C. END USE AND DISPOSAL EMISSIONS

1. Aerosol Propellants

a. Introduction - The fluorocarbons are one of three major types of propellants used in aerosol products today. The other two are hydrocarbons and compressed gases. Some of the important characteristics of each type and factors which affect the selection of a specific type for a given aerosol are discussed in the sections which follow. The fluorocarbons and hydrocarbons are characterized as liquified gas propellants. They are gases at normal room temperature and pressure, but become liquified when compressed and confined under pressure in an aerosol container.

Sketches of several different types of aerosol containers are shown in Figure IV-1. In the case of the liquified propellants, the vapor pressure of the liquid, confined at a temperature above its normal boiling point, provides the propellant force. When the actuator button is pressed, opening the valve, the pressure forces the contents through the valve orifice and out the nozzle in the form of a spray, mist, foam or steady stream depending on the type of delivery desired.

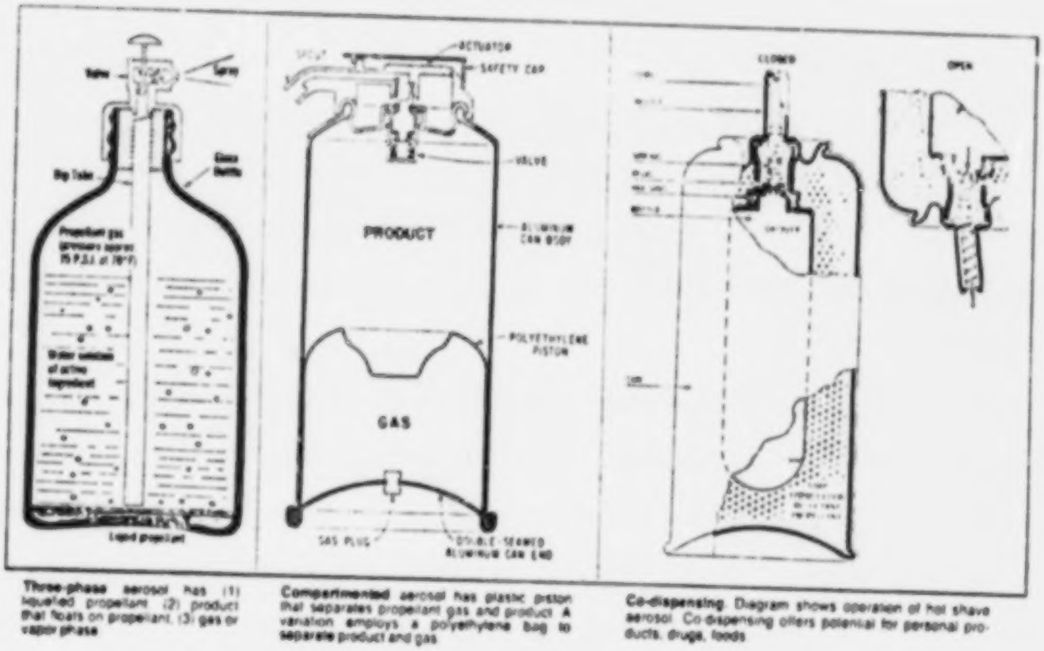
An important advantage of liquified propellants is that they provide relatively uniform pressure over the life of the product. Vapor pressure is dependent on temperature, but since most aerosols are used at or near room temperature, pressure variations are relatively small. Another advantage of liquified gas propellants is that they form part of the solvent system and as such provide a "burst" effect. In other words, as the solution leaves the nozzle, the propellant immediately vaporizes or flashes off from the solution. This vaporization aids in producing a fine (true aerosol) spray.


COMPRESSED GAS
PROPELLANT
LIQUID
CONCENTRATE
Operates by pressing down
Aerosol spray
Propellant gas pressure approx. 35 p.s.i.g. at 70°F
Vapor phase
Liquid phase
Solution of propellant and active ingredients
Dip tube
Propellant pressure approximately 40 p.s.i.g. at 70°F
vapor phase
Liquid phase
Emulsion of propellant water perfume active ingredients
Operates by pressing to one side
Aerosol foam

Single-phase aerosol is powered by (1) compressed gas. This type is used for whipped cream.

Two-phase spray or mist aerosol has (1) liquefied propellant in solution with product, (2) gas or vapor phase to supply pressure. This type is used for majority of aerosols.

Two-phase foam aerosol has (1) liquefied propellant in emulsion with product, (2) gas or vapor phase. Typical use is shave foams.


Valve
Spray
Dip Tube
Glass Bottle
Propellant gas (pressure approx. 75 P.S.I. at 70°F)
Water solution of active ingredient
Liquid propellant
SPOUT
ACTUATOR
SAFETY CAP
VALVE
PRODUCT
ALUMINUM CAN BODY
POLYETHYLENE PISTON
GAS
GAS PLUG
DOUBLE-SEAMED ALUMINUM CAN END
CLOSED
OPEN

Three-phase aerosol has (1) liquefied propellant, (2) product that floats on propellant, (3) gas or vapor phase.

Compartmented aerosol has plastic piston that separates propellant gas and product. A variation employs a polyethylene bag to separate product and gas.

Co-dispensing. Diagram shows operation of hot shave aerosol. Co-dispensing offers potential for personal products, drugs, foods.

Figure IV-1. Types of Aerosol Containers

Source: Modern Packaging Encyclopedia, 1972/73.

In powder sprays, the liquified propellant serves as the suspending medium for the powder. The burst effect and rapid evaporation of the propellant make it possible to deliver a "dry" spray. This is considered an important feature, for example, for anti-perspirants. Background and detailed discussion of aerosol technology may be found in a variety of sources, including the Aerosol Handbook.[a]

Fluorocarbons are used as aerosol propellants, even though they are more expensive than other propellants, because they offer an advantageous combination of properties including:

- Safety - nonflammable and a low order of toxicity,
- Liquified gas form - advantages of this feature have been described above,
- Versatility - fluorocarbons can be blended to provide a range of pressures and solubility characteristics,
- Chemical stability/inertness - little or no deleterious effect on other components of product formulation or on the container, and
- Odorless - especially important for perfume formulations.

Nonflammability is probably the single most important attribute since this characteristic, more than any other, distinguishes fluorocarbon from hydrocarbon propellants.

The three major fluorocarbon propellants are F-11, F-12 and F-114. A few other fluorocarbons are used in only relatively minor amounts; these include F-115, F-22, F-142b, and F-152a. Physical properties of these compounds are included in Table IV-1. Fluorocarbon C-318 was used in some aerosol food products, but has been supplanted by F-115. Fluorocarbon 12 has a relatively

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[a] The Aerosol Handbook, Johnsen, et al. editors, W. E. Dorland Co., 1972.

Table IV-1. PHYSICAL PROPERTIES OF AEROSOL PROPELLANTS

Propellant Types	Chemical Formula	Boiling Point, °F	Vapor Pressure		Kauri-Butanol Value[a]	Flammability Limits Vol % in Air	Toxicity[b] Rating
			70°F	130°F			
Fluorocarbons							
F-11	CCl_3F	74.9	13	39	60	nonflammable	5
F-12	CCl_2F_2	-21.6	85	196	18	nonflammable	6
F-114	$CClF_2CClF_2$	38.8	27	73	12	nonflammable	6
F-115	$CClF_2CF_3$	-38.4	120	267	7	nonflammable	6
F-21	$CHCl_2F$	48.1	23	65	102	nonflammable	4 to 5
F-22	$CHClF_2$	-41.4	136	312	25	nonflammable	5a
F-142b	CH_3CClF_2	15.1	44	107	20	9.0 to 14.8	-
F-152a	CH_3CHF_2	-13	76	191	11	5.1 to 17.1	6
F-C318	C_4F_8	21.5	40	107	5	nonflammable	6
Hydrocarbons							
Propane	C_3H_8	-43.8	124	274	-	2.2 to 9.5	5
Isobutane	$i\text{-}C_4H_{10}$	10.9	45	110	-	1.8 to 8.4	5
n-Butane	$n\text{-}C_4H_{10}$	31.1	31	81	-	1.9 to 8.5	5
Dimethyl Ether	CH_3OCH_3	-12.7	78	187	-	3.4 to 18.0	-
Compressed Gases							
Carbon Dioxide	CO_2	-	852	-	-	nonflammable	5a
Nitrous Oxide	N_2O	-127	735	-	-	nonflammable	-
Nitrogen	N_2	-320	-	-	-	nonflammable	-
Chlorocarbons							
Methylene Chloride	CH_2Cl_2	104	7	24	136	nonflammable	4 to 5
Methylchloroform	CH_3CCl_3	165	2	7	117	nonflammable	-
Methyl Chloride	CH_3Cl	-10.6	74	174	+100	7.6 to 19.0	4
Ethyl Chloride	CH_3CH_2Cl	54.3	20	56	-	3.8 to 15.0	4

a. Higher number indicates stronger solvent power.

b. Underwriters Laboratory Toxicity Rating System - 6 least toxic, as a reference point, carbon dioxide is class 5a.

Sources:
1. DuPont and Allied Chemical Trade Literature.
2. Modern Packaging Encyclopedia, Sept., 1967.
3. The Aerosol Handbook, Johnsen et al. editors, 1972.

high vapor pressure and is used to provide the pressure or propelling force in many formulations. To maintain pressure at a safe level in the container, F-12 is used in combination with a vapor pressure depressant, either a higher boiling fluorocarbon or another organic solvent. Typically F-11 is blended with F-12 to reduce pressure and to improve solubility and compatibility with other components of the formulation. Fluorocarbon 114 is used alone or in blends with F-12 primarily in colognes, perfumes, and some specific brands of personal care products.

b. Emission Sources - An estimate of fluorocarbon emissions to the atmosphere in the form of aerosol propellants, based on 1973 U.S. consumption of aerosol products is given in Table IV-2. The total 1973 propellant emissions for fluorocarbons F-11, F-12 and F-114 were slightly greater than 500 million pounds. Based on estimates of 1974 sales of aerosol products, emissions in 1974 were approximately 90 percent of the 1973 level. These totals include losses of propellant during filling of the aerosol containers, estimated by industry sources to be on the order of 3 percent of the total propellant charge.

As indicated in Table IV-2 hair sprays and anti-perspirants (plus deodorants) are the two largest categories for fluorocarbon emissions--representing approximately 75 percent of the total emissions as aerosol propellant. Fluorocarbon propellants are used in more than 90 percent of the medical and pharmaceutical aerosol products. This category accounted for emissions of approximately 17 million pounds of F-11 and F-12 in 1973, or about 4 percent of total fluorocarbon propellant emissions. Fluorocarbon propellants are used to some extent in many other aerosol product categories, but either

Table IV-2. ESTIMATED U.S. FLUOROCARBON EMISSIONS AS AEROSOL PROPELLANT[a] BY PRODUCT TYPE - 1973

Aerosol type	Aerosol unit estimates[a]					Fluorocarbon propellant emission estimates (millions of pounds)				
	Millions of units filled	Percent of units Propelled by F.C.	Average weight (lb/unit)	Average Percent Propellant Per unit		F-11 emissions	F-12 emissions	F-114 emissions	Total F.C. emissions	Percent of total
Personal										
Hair care	469	95	0.8	50		103.0	72.0	3.4	178.4	35.0
Antiperspirants and deodorants	577	95	0.6	65		85.5	114.3	7.0	206.8	40.4
					Subtotal	188.5	186.3	10.4	385.2	75.4
Medicinal and pharmaceutical	66	90	0.4	80		11.0	5.5	3.0	19.5	3.8
Colognes and perfumes	144	95	0.1	45		-	1.0	6.7	7.7	1.5
Shave lathers	171	10	0.6	10		-	0.4	0.6	1.0	0.2
Others	70	80	0.5	60		7.5	7.5	1.0	16.0	3.1
					Subtotal	18.5	14.4	11.3	44.2	8.6
Household										
Room deodorants	170	20	0.5	50		2.7	5.0	-	7.7	1.5
Cleaners	211	10	0.9	20		2.1	2.1	-	4.2	0.8
Laundry products	163	20	0.9	35		4.2	6.0	-	10.2	2.0
Waxes and polishes	105	30	0.8	15		1.5	2.5	-	4.0	0.8
Others	43	25	0.8	50		2.0	2.0	-	4.0	0.8
					Subtotal	12.5	17.6	0.0	30.1	5.9
All Other Products										
Insecticides	143	30	0.9	40		5.5	9.0	-	14.5	2.8
Coatings	268	10	0.8	45		3.4	6.6	-	10.0	2.0
Industrial	132	30	0.9	50		6.0	11.0	-	17.0	3.3
Foods and pan spray	115	5	0.8	65		-	-	3.0	3.0	0.6
Automotive	89	15	0.8	30		1.0	2.5	-	3.5	0.7
Vet. and pet	16	50	0.5	50		0.5	0.5	-	1.0	0.2
Others	34	40	0.6	30		1.0	1.5	-	2.5	0.5
					Subtotal	17.4	31.1	3.0	51.5	10.1
Total Units Filled	2,986									
Total Emissions (millions of pounds)						236.9	249.4	24.7	511.0	100.0
Percent of F.C. Propellant Emissions						46.4	48.8	4.8	100.0	

[a] Use and filling emissions for products produced in 1973; emission lag averages 6 months for most products; some unit estimates have been rounded.

Sources: Chemical Specialties Manufacturers Association and Arthur D. Little, Inc. estimates based on industry contacts.

because these other categories are small or because fluorocarbons are used in only a small portion of the units, the total fluorocarbon emissions from all other categories is relatively minor, with no one group of products accounting for more than 4 percent of total fluorocarbon propellant emissions.

c. Alternatives - Potential alternatives to the presently used fluorocarbon propellants are described below. Physical properties of these alternatives are included in Table IV-1.

Other Fluorocarbons - Based on discussions with fluorocarbon producers, the possibilities for substituting other fluorocarbons that are potentially less stable in the atmosphere due to the presence of hydrogen atoms or unsaturation are very limited. Unsaturated fluorocarbons are characterized as generally toxic and therefore unacceptable as propellants. As more hydrogen atoms are added, the fluorocarbons become flammable. Fluorocarbon 22 might be a substitute for F-12 in some cases, but some producers question whether it would also be found to pose a significant threat to atmospheric ozone. Fluorocarbons F-31, F-32, F-142 and F-152 are all flammable and therefore lack a key advantage of the current fluorocarbon propellants. There is also a problem in finding an acceptable substitute for the lower boiling component, typically F-11, used as a vapor pressure depressant and solvent. Use of F-21 as a low-pressure component would be possible at a reasonable cost, but since it is a very strong solvent, it is likely to act as a skin irritant if present as a substantial portion of the propellant system. Therefore, it is questionable whether fluorocarbon 21 would be suitable for use in personal products--which represent the major use for fluorocarbon propellants.

Assessment of the possibility of using perfluorocarbons (containing only carbon and fluorine) as propellants is difficult at this point. Producers indicate that such compounds would be more complex, higher molecular weight species, which would be considerably more expensive than the simpler products presently manufactured commercially. DuPont has offered F-C318 (perfluorocyclobutane) in limited quantities in the past, particularly for food products, but this use has been supplanted by F-115. DuPont estimates that the cost of F-C318 might be five to ten times that of F-11 even with large scale commercial production. Other perfluoro compounds (e.g., perfluoropropane, perfluoro-n-butane and perfluoroisobutane are currently being produced only in experimental quantities.

The manufacturers of these compounds estimate that commercial prices for one of these compounds, perfluoropropane, would be on the order of $2 to $6 per pound depending on the scale of operation. (This price range is about ten times the price of F-11 and F-12.) In addition to higher cost, the perfluorocarbon compounds have the important disadvantage of being generally poor solvents.[a]

Hydrocarbons - Hydrocarbons used as liquefied gas propellants include isobutane, propane, n-butane, and dimethyl ether. Isobutane and propane are the two which are most widely used. Hydrocarbons offer most of the performance features of fluorocarbons and are appreciably lower in cost. However, they are highly flammable, and this has prevented their general use as substitutes for fluorocarbons. In some instances, minor amounts of hydrocarbon are blended with halocarbons to reduce costs. The proportions used are such that the halocarbons suppress flammability.

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[a] An ideal propellant has high enough solvent power to dissolve the product ingredients but is not strong enough to irritate the skin.

addition to fluorocarbons, C_1 chlorocarbon derivatives include tetramethyl lead, silicones, solvents, and others which find end uses in polymers, paints, aerosols, gasoline anti-knock agents, and numerous other end uses. Table VI-4 summarizes C_1 chlorocarbon derivative end-use applications and their respective amounts of chlorocarbon intermediates consumed in 1973.

C_2 chlorocarbon derivatives likewise find widespread and important end uses. Most notable is polyvinyl chloride, a versatile and cost-effective plastic, which accounted for over 4.5 billion pounds or nearly 86 percent of vinyl chloride production in 1973. PVC production alone accounted for nearly 15 percent of total U.S. chlorine demand in 1973. Other important C_2 chlorocarbon derivatives include tetraethyl lead, ethylene amines, polyvinylidene chloride and others which find end uses in textiles, gasoline anti-knock compounds, solvents, and in export markets. In addition, substantial amounts of two C_2 chlorocarbons, perchloroethylene and trichloroethylene, are used directly as dry cleaning and metal degreasing agents. Table VI-5 summarizes 1973 C_2 chlorocarbon derivative end uses and volumes.

2. Chlorocarbon and Fluorocarbon Product and Material Flows

a. Chlorocarbon Intermediates

Figure VI-2 summarizes in greater detail the product and material flows of the fluorocarbons under consideration and their intermediate chlorocarbon precursors, carbon tetrachloride, chloroform, and perchloroethylene. As pointed out in the previous section, these three materials are only several of the many C_1 and C_2 chlorocarbon intermediates which are highly interrelated by virtue of either common primary intermediate precursors or similar derivative end products. Chloroform and carbon

Carbon dioxide and nitrous oxide have considerably greater solubility in the liquid phase of aerosol formulations and, therefore, are preferred over nitrogen as propellants. However, they share many of the undesirable pressure characteristics of nitrogen and until recently have been used primarily only in foams or such products as furniture polishes and windshield de-icers where coarser sprays are satisfactory. Nitrous oxide has the further disadvantage of being a powerful oxidizing agent - a property which greatly increases the flammability of products propelled with this gas.

Recent developments announced by valve manufacturers and carbon dioxide suppliers indicate that there may be some potential for use of carbon dioxide as a propellant to replace fluorocarbons. An assessment of this possibility is presented below under "Technical and Economic Evaluation."

Chlorocarbons - Several chlorocarbons -- methyl chloride, ethyl chloride, and vinyl chloride -- have been considered as potential propellants by virtue of their low to moderate vapor pressures. However, they are also noted for undesirably high solvent power, toxicity, and flammability. Vinyl chloride was formerly used to an appreciable extent in propellant blends, but its use has been banned because of its carcinogenic properties. None of these are viable alternatives to fluorocarbon propellants.

Methylene chloride is the most important of the chlorocarbons used in aerosols. It does not have adequate vapor pressure (b.p. 104°F) to serve as a propellant but is used as a higher boiling component for its combination of nonflammability, solvent properties, and relatively low cost.

Another chlorocarbon solvent used for similar reasons is methyl chloroform. Methylene chloride is used as a partial replacement for fluorocarbons in some hair sprays to reduce product costs, however, because of its strong solvent action it tends to act as a skin irritant. Typical concentration levels are less than 10 percent to avoid a significant incidence of skin irritation. One large chemical manufacturer has promoted a hair spray propellant system based on a mixture of methylene chloride and nitrous oxide, but this system has not achieved commercial acceptance because of the irritation problem. Further work may resolve this problem.

Mechanical Devices - There are many mechanical devices or other delivery systems which may be cited as potential alternatives to the fluorocarbon propelled aerosols. Many products are currently offered in both aerosol and non-aerosol forms. An alternative in some cases would be to return to the product form which was used prior to the aerosol form. However, aerosol proponents argue that in many applications there is no equally effective, convenient, and satisfactory means for dispensing the product. Examples range from hair sprays and anti-perspirants to insecticides and certain medicinal and pharmaceutical products.

Finger- or hand-activated mechanical pumps represent an area of considerable interest and development effort. A pump-based hair spray was brought on the market in 1972, and at least seven companies now offer hair sprays, both men's and women's that use pump delivery systems. Standard test methods for evaluating performance characteristics of pumps have been proposed, and a number of companies making these pumps are having difficulty meeting current demand. The current demand level is on the order of 50 to 60 million pumps per year for hair care products. This is approximately 13 percent of the number of aerosol hair care units which were marketed in 1974.

At least two container designs which are capable of pressure dispensing without the use of propellant are available. One design utilizes an expendable rubber bladder inside a rigid outer container. The recovery force of the bladder, expanded with the product during filling, provides the dispensing pressure. Another container utilizes a compressed steel spring to deliver a burst of spray from a dispensing chamber. The container is a two-part design. The user reloads the spring for each burst of spray by rotating the bottom part of the container 180°. The development and evaluation of these designs is still underway, but due to limited pressures, spray delivery characteristics, and cost of the containers, it appears unlikely that either of these designs offers a viable alternative for most personal aerosol products.

Several manufacturers have available container designs characterized as "bag-in-can" types. In these containers the product is held in a plastic pouch or bag mounted within a conventional aerosol can. These delivery systems require the use of some type of conventional propellant but the propellant is not released until the can is destroyed or recycled. Several technical and cost problems have yet to be solved for these systems.

Other product forms or delivery systems of the non-aerosol type that can be cited to compete effectively with current aerosols and their other alternatives include such items as squeeze bottles, roll-on applicators, stick-type applicators, squeeze tubes, wick-type dispensers, saturated pad applicators, felt tip applicators, and products which can be applied by hand from a glass or plastic container.

d. Potential Environmental Hazards of Alternatives - The various propellant alternatives discussed above should be examined in terms of possible adverse environmental effects which could result from their replacement of fluorocarbons 11 and 12. This assessment seems more difficult in view of the unsuspected environmental hazard which has, in theory, been linked to long-term atmospheric emissions of F-11 and F-12.[a] Nevertheless, it is important to review the environmental characteristics of the alternatives so that other known hazards are not created through substitution. Some environmental characteristics of fluorocarbons, hydrocarbons, compressed gases and chlorocarbons are discussed below.

Other Fluorocarbons - In view of the current ozone destruction hypothesis, other fluorocarbons must be assessed in terms of stability in the lower atmsophere as well as with respect to toxicity ratings and other possible environmental hazards. According to current belief of scientists, who are studying the ozone depletion hypothesis, molecules containing carbon-carbon double bonds or carbon-hydrogen bonds should be susceptible to attack by OH radicals in the lower atmosphere and should therefore have relatively short (e.g. 1-5 year) atmospheric residence times. On the other hand, saturated perfluorocarbons (containing only carbon and flourine atoms) could be so stable that environmental effects would be negligible for an indefinite period. At this point the long-term effects of a build-up of stable synthetic halocarbons in the atmosphere are not fully understood and further studies of the possible environmental hazards of these compounds are now underway.

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[a] The scope of this study did not include an assessment of the ozone depletion hypothesis and no judgement on this question should be inferred here, or elsewhere in the report.

Hydrocarbons - Propane and various saturated isomers of butane are by far the predominant hydrocarbon propellants today. As paraffins, these compounds exhibit low photochemical reactivity and are exempt compounds under Rule 66 of the Los Angeles County Air Pollution Control District. Furthermore, when comparing the potential magnitude of hydrocarbon emissions as aerosol propellant to total hydrocarbon emissions from other sources, it appears that the environmental impact of substituting hydrocarbons for fluorocarbons in this application would be small. For example, if the total 1973 fluorocarbon propellant emissions of approximately 500 million pounds were replaced pound-for-pound by hydrocarbon emissions, these emissions would represent less than one percent of national hydrocarbon emissions in 1970 as estimated by the U.S. Environmental Protection Agency.[a] In the past, the flammability of these compounds (which may be suppressed with halocarbons) has mitigated against their use in those products where fluorocarbons are most widely used.

Compressed Gases - For the quantities which would be involved in aerosol spray applications, the compressed gases would be unlikely to present an environmental hazard. Nitrogen, carbon dioxide and nitrous oxide are all natural components of the atmosphere. Nitrogen makes up approximately 75 percent, carbon dioxide 0.05 percent and nitrous oxide about 0.00016 percent by weight of the earth's atmosphere.[b] Even for nitrous oxide, the quantity of atmospheric emissions which would result from substituting this compressed gas for current world-wide use of F-11 and F-12 as aerosol propellants would be less than one-tenth of one percent of the estimated annual global emissions of nitrous oxide from biological action. Unfortunately, as was noted earlier, these gases are far from ideal aerosol propellants for many applications. None of them will deliver a fine spray with current technology, nitrogen has very poor solubility properties, and nitrous oxide presents a direct personal hazard because of its strong oxidizing power.

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[a] The National Air Monitoring Program: Air Quality and Emissions Trends Vol. 1, EPA, 1973. Table I-5.

[b] Bolz, R.E., and G.L. Tuve, (eds.), Handbook of Tables for Applied Engineering Science, The Chemical Rubber Co., Cleveland, 1972. P. 533.

Chlorocarbons - These compounds are undesirable as broad substitutes for the fluorocarbon propellants because of the direct human hazards they would present in terms of flammability, toxicity and skin irritation. In view of these characteristics, no assessment of possible environmental hazards is presented here.[a] It is worth noting, however, that methyl chloride has been identified as a possible source of stratospheric chlorine atoms. Although a natural source is believed to exist for much of the methyl chloride present in the atmosphere, substitution of methyl chloride for F-12 as a propellant would increase estimated U.S. anthropogenic emissions of this chemical by a factor of about thirty.

e. Technical and Economic Evaluation of Aerosol Alternatives - The approximate selling prices (mid-1975) of the various major types of aerosol propellants in use are listed by Table IV-3. The fluorocarbons, clearly, are the most expensive propellants among those commonly in use. One industry source estimated that in his company's aerosol product line, fluorocarbon propellants represent, on the average, about 30% of the direct product cost. If direct substitution of alternative propellants such as hydrocarbons

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[a] Recent work by one producer suggests that methylene chloride may be substituted as vapor depressant, in small quantity without causing flammability, skin irritation or toxicity hazards. Also, since the hydroxyl reactivity rate of methylene chloride is relatively high, it probably poses less of a threat to the atmosphere than the more stable fluorocarbons.

Table IV-3. APPROXIMATE SELLING PRICE OF MAJOR AEROSOL PROPELLANTS - 1975
(cents per pound)

Propellant types	Price[a]
Fluorocarbons	
F-11	35
F-12	41
F-114	49
F-115	150
Hydrocarbons	
Propane	14
Isobutane	12
n-Butane	12
Compressed gases	
Carbon dioxide	5
Nitrous oxide	19
Nitrogen	3
Chlorocarbon	
Methylene chloride	17

[a] Price will vary considerably depending on quantities purchased and shipping costs. These are prices to aerosol fillers.

Source: Arthur D. Little, Inc., estimates based on industry contacts.

were possible, propellant cost would be reduced to about 10 percent of product cost. There have been strong economic incentives, therefore, for producers of aerosol products to use alternative propellants, wherever possible, to formulate marketable products. However, in the absence of regulatory controls, the market place, however imperfect, ultimately serves to determine which product or products the consumer finds most satisfactory on a cost/performance basis. Historically, the consumer has found fluorocarbon products to be most satisfactory in many cases.

There seems to be a general consensus among aerosol industry representatives that it is not possible to make a direct substitution of one type of propellant for another or substitute a mechanical delivery system for an aerosol system without significantly altering the characteristics of the product in question. Thus, assessment of the technical feasibility of alternatives to fluorocarbon based aerosols is difficult because of the many subjective product qualities involved as perceived by the consumer. The convenience of aerosols relative to mechanical applicators is one example; the unpleasant feel of a wet, cold spray on the skin is another. In hair sprays, a pump spray may be more satisfactory for a particular hair style than an aerosol product, or vice-versa. The desired amount of 'holding power' and the 'feel' of the hair are important considerations according to aerosol hair spray marketers.

A number of pump type hair sprays are currently on the market, as noted previously. The pumps used in these products cost approximately 10 to 15¢. In a comparison with aerosol spray systems, the pump can be viewed as a replacement for both the aerosol valve and the propellant.[a] The valve and overcap for fluorocarbon aerosol products cost approximately 3 to 4¢. Propellant costs obviously depend on the amount used, which in turn depends on specific formulation and size or weight of the product. The combinations of F-11 and F-12 typically used cost about 40-45¢/lb including filling losses. Other manufacturing costs include the container, filling costs, and non-propellant formulation components such as working ingredients and solvent. A current problem with pumps is that leakage occurs, both of air into the container (always), and of contents out of the container if the container is not kept upright. To prevent leakage until the product reaches the consumer, most pump products are sealed with a cap. The products are packaged in individual cartons (an added cost) which include the detached pump unit. Products which are sensitive to oxidation or degradation by the air cannot be packaged as pump sprays.

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[a] But not a total replacement since the product must be reformulated with additional solvent to replace solvent power of the propellant.

Hair sprays based on carbon dioxide (CO_2) propellant are at various stages of development. Introduction of special valves that improve spray characteristics has helped spur interest in CO_2. We understand that at least one CO_2-based hair spray is currently undergoing limited market testing. Carbon dioxide costs approximately 3 to 7¢ per pound and is used at a level of 3 to 5 percent of total content weight. Propellant cost, therefore, is much less than for fluorocarbons. As in the case of the pump spray, alternative formulations are required due to differences in the delivery or propellant system. For example, more solvent must be used with a CO_2 system to replace the liquid fluorocarbon propellant. The added solvent helps to dissolve CO_2 and thus maintain a constant delivery pressure. The special CO_2 valve presently costs 1 to 2¢ more than the standard valve and a slightly more costly can is used as a precaution against the somewhat higher pressure of the CO_2 system. Filling costs are on the order of 1-2¢ per unit higher because of the saturation step required with CO_2.

Aerosol products are labeled and marketed on a total contents weight basis; i.e., the weight of propellant is included in the product weight. Since there is no propellant in a pump spray and since a carbon dioxide aerosol spray contains much less propellant than a fluorocarbon aerosol, there is some question as to the content weight which constitutes an equivalent amount of product in each case. As noted above, differences in formulation required to meet desired performance characteristics are also involved. For example, use of additional solvent may be one method to at least partially replace liquified propellant. Furthermore, a marketing strategy may be adopted whereby the alternatives are either marketed at the same total content weight or in the same size package as the fluorocarbon propelled aerosols. These factors complicate any direct cost comparison.

The general consensus of the industry at this point seems to be that pump sprays presently cost slightly more than fluorocarbon aerosol sprays while CO_2-based products cost slightly less.[a] Again, it is worth repeating that any comparison of costs should be viewed with the understanding that the product performance characteristics of each of the alternatives are different.

Hydrocarbon-based hairspray products in which water was included in the formulation to suppress flammability were on the market at one time several years ago. They reportedly were less costly than fluorocarbon based products, but they never achieved successful consumer acceptance and were eventually withdrawn from the market. In the anti-perspirant product category, there has been no widely acknowledged success to date in the use of compressed gas or hydrocarbon propellants. (One industry source reports that an anti-perspirant formulated with a methylene chloride/hydrocarbon propellant system has been marketed on a limited scale for several years.) Developments are underway on pump-based products, and a product of this type is reportedly undergoing limited market tests. Alternative product forms already on the market, and in apparently increasing quantities, include roll-ons, sticks, and pad-type products. There has been an effort to promote forms which spray a dry powder, but these are criticized on the basis that most of the powder does not adhere to the skin. Another possibility, if fluorocarbon-based anti-perspirants were to be banned, is that there would be a resurgence of deodorant aerosols--provided that these can be formulated with an alternative propellant such as CO_2.

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[a] This comparison is on a total product weight basis, including aerosol propellant.

Information on perfluorocarbon compounds under evaluation as propellants is limited because interest in them was generated only recently by the threat of possible restrictions on the use of F-11 and F-12, and also because of confidentiality agreements between formulators and suppliers. However, at projected commercial prices of $2 or more per pound, they would be at a severe, if not prohibitive, cost disadvantage relative to the other alternatives--except perhaps in high-cost specialty items such as perfumes or medical/pharmaceutical products.

2. Refrigerants

a. End Use - The end use of fluorocarbons in refrigeration and air conditioning is distributed between R-11[a], 12 and 22, accounting for all but a few percent of the total refrigerants sold. The estimated quantities used are shown in Table IV-4.

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[a] The 'R' in this terminology is an abbreviation for 'refrigerant' and is equivalent to the 'F' code used for fluorocarbons in other sections of this report.

Table IV-4. END USE OF FLUOROCARBON REFRIGERANTS BY TYPE

Fluorocarbon	1973 End Use (millions of pounds)	1973 End Use (percent)
R-11	18	6
R-12	168	56
R-22	90	30
Other	24	8
Total	300	100

Source: Arthur D. Little, estimates based on industry data.

An estimate of 1973 fluorocarbon refrigerant use and emissions to the atmosphere is shown in Table IV-5. This table is based on data compiled by industry associations, the U.S. Department of Commerce, fluorocarbon producers and refrigeration and air-conditioning equipment manufacturers. The individual emission estimates are calculated from unit data, using the assumptions given on the table.

b. Emission Problem Areas - As indicated in Table IV-5, fluorocarbon emissions from automobile air-conditioning, from residential and commerical air-conditioning, and from food store refrigeration are all relatively large. Approximately 80 percent of the fluorocarbon refrigerant emissions are derived from air-conditioning applications. It appears that more than 60 percent of all refrigerant emissions could be eliminated with improved service procedures and with relatively minor design changes. Another 25 percent of emissions could be recovered at the point of disposal, and the remaining 15 percent eliminated only by changing to a different refrigerant.

Table IV-5. ESTIMATED U.S. FLUOROCARBON EMISSIONS AND USE AS REFRIGERANT - 1973

Type of equipment[b]	Refrigerant commonly used	Units in service (millions)	Units shipped 1973 (millions)	Units scrapped 1973 (millions)	Average unit charge (lb/unit)	Original charge 1973 (million lb)	Leakage not recoverable (million lb)	Preventable leakage[a] (million lb)	Recoverable refrigerant at disposal (million lb)	Total emissions (million lb)	Percent of Total
		Unit Estimates					Emission Estimates[b]				
Major Appliances											
Room A/C [1]	22	29.0	5.35	4.00	2.00	10.7	1.2	Small	6.4	7.6	3.6
Dehumidifiers[1]	12	5.1	0.65	0.16	0.84	0.5	0.1	Small	0.1	0.2	0.1
Freezers[1]	12	22.4	2.42	1.10	1.25	3.0	0.6	Small	1.1	1.7	0.8
Refrigerators [1]	12	68.7	6.77	4.00	0.63	4.3	0.9	Small	2.0	2.9	1.4
Other											
Ice makers[1]	12	1.3	0.22	0.03	2.00	0.4	0.1	Small	0.1	0.2	0.1
Water coolers [1]	12	3.8	0.39	0.16	1.00	0.4	0.1	Small	0.1	0.2	0.1
Mobile A/C[4]	12[c]	45.0	7.53	7.00	3.80	28.6	6.8	42.8	21.3	70.9	33.3
Unitary residential[2] A/C	22	11.4	2.15	0.40	9.20	19.8	2.1	12.6	2.9	17.6	8.3
Unitary commercial[2] A/C	22	4.0	0.62	0.17	36.0	22.3	2.9	17.3	4.9	25.1	11.8
Centrifugal chillers[3]	11,12,22	0.05	0.005	0.001	2500	12.5	6.3	15.0	2.0	23.3	11.0
Reciprocating chillers[2]	11,12,22	0.2	0.02	0.003	350	7.0	1.4	8.4	0.8	10.6	5.0
Unit coolers [1]	12	1.7	0.19	0.12	14.0	2.7	0.5	Small	1.3	1.8	0.8
Food store refrig.[d,3]	12,22	0.2	0.008	0.006	675	5.4	6.8	16.2	3.2	26.2	12.3
Mobile refrig. [2]	12	0.5	0.07	0.03	14.0	1.0	0.1	0.8	0.3	1.2	0.6
Beverage refrig. [2]	12	23.8	3.57	0.65	1.2	4.3	0.6	3.4	0.6	4.6	2.2
Packaged terminal[1] A/C	22	1.0	0.15	0.03	2.5	0.4	0.1	Small	0.1	0.2	0.1
Other	-	-	-	-	-	9.0	2.2	11.9	3.9	16.0	8.5
Total	-	-	-	-	-	132.3	32.8	128.4	51.1	212.3	100.0

Small = less than 0.1 million pounds

[a] Preventable through relatively minor modifications to current equipment design or service procedures.

[b] Emission basis:

1. Factory charged, sealed units: 2 percent of charge per year basic leakage (not recoverable).
2. Field charged sealed compressor units: 2 percent basic leakage and 12 percent service- and design related (potentially preventable).
3. Field charged open motor units: 5 percent basic leakage and 12 percent service- and design-related (potentially preventable).
4. Mobile (automobile) A/C unit: 4 percent basic leakage and 25 percent service- and design-related (potentially preventable).

1-4. Refrigerant charge remaining at time of scrap is equal to 80 percent of original charge.

[c] R-22 is used in busses.

[d] Unit data are on a per store basis.

Sources: U.S. Department of Commerce and Arthur D. Little, Inc., estimates based on industry contacts.

c. Identification of Potential Solutions - Potential solutions to fluorocarbon losses of refrigerants may be classified as follows:

- Leak prevention,
- Recovery during servicing or disposal,
- Use of alternate refrigerants or refrigeration systems, and
- Reduction or elimination of refrigeration and air conditioning.

Alternate refrigerants will be discussed in detail in Section d, "Evaluation of Chemical Alternatives."

A short discussion of refrigeration systems is given below, as background for understanding the potential solutions discussed. Figure IV-2 illustrates the basic vapor-compression refrigeration system, which is the most widely used refrigeration cycle today.

The cycle consists of compression of the refrigerant gas, cooling by water or air to convert the gas to liquid, and expansion through a valve to permit evaporation of the liquid. Evaporation absorbs heat from the refrigerator unit or air being conditioned. The warmed refrigerant then renews the cycle at the compressor. There are many variations, including more complex cycles, in order to provide designs that are optimized for particular applications.

Leak Prevention - Leakage losses are at a relatively low level for hermetically[a] sealed systems, being reported at about 2 percent of the initial charge per year, based on a 10-year life with about 80 percent of charge left at that time. This rate appears to be about the best the state-of-the-art is capable of since home refrigerators and window air conditioners are mature,

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[a] In the air conditioning and refrigeration industry, the term "hermetic" is taken to mean a system in which the compressor drive motor is sealed in the refrigerant atmosphere.

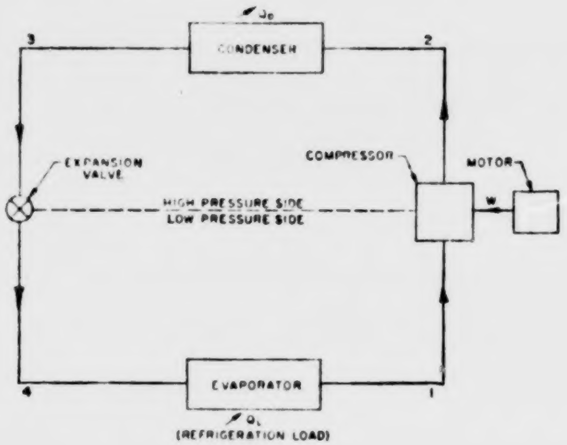
Q_H
3
CONDENSER
2
EXPANSION VALVE
COMPRESSOR
MOTOR
HIGH PRESSURE SIDE
LOW PRESSURE SIDE
W
4
EVAPORATOR
1
Q_L
(REFRIGERATION LOAD)

Figure IV-2. Equipment Diagram for Basic Vapor Compression Cycle

Source: ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., Joseph D. Pierce, Chairman, 1972.

highly competitive products, and do not use mechanical connectors nor elastomer seals.

Non-hermetically sealed systems on the other hand have substantial losses; two general categorizations appear reasonable for this class: mobile and stationary.

The dominant subcategory of mobile systems is the automobile air conditioner. Auto air conditioners are reported as leaking at a rate of 2-3 ounces per year per unit, but overall losses are reported as closer to 16 ounces per year per unit. The larger figure is due to the practice of service stations promoting refrigerant recharging, with the spent charge being lost to the atmosphere. As in the case of home appliances, the product is mature and well engineered, with the rotating shaft seal and the flexible hoses as leak sources. Leaks from the rotating seal may show small reduction by using two series seals, but this would add cost and add to the power requirements to overcome the added friction--with little reduction in emissions.

A greater point of leverage to reduce losses in auto air conditioners is to modify the flexible elastomer hose. This hose has a very high permeability at the high temperatures (150°F) under the hood. To shorten it would probably help but wouldn't attack the basic problem, and would result in a greater transmission of noise and vibration to the cab. A more basic approach is to replace the elastomer hose with flexible metal hose. The three flexible hoses commonly used represent between 5 and 10 percent of the manufacturing costs of a system. Hose manufacturers indicate that they have not yet achieved metal flexible hoses that will stand up to the vibrations as the auto A/C system is presently designed. However, the failure mode has been postulated as due to torsion from engine rock, which could be alleviated by extra length of hose, providing a loop. A further significant reduction of losses may be achieved through reduction in service losses, which is discussed in that section later in this report.

The other category of non-hermetically sealed systems is that of stationary systems. One subcategory is represented by unitary commercial air conditioners, another by large commercial refrigeration and air conditioning systems (chillers). These subcategories are characterized by field assembly and charging. Since mechanical tubing connectors are used, such systems are prone to leak rates in the order of twice those found in hermetically sealed systems; resulting in an average charge life of 5 rather than 10 years.

Precharged compressor units that contain the bulk of the necessary charge sealed within by self-sealing connectors are reported to be in about 40 to 50 percent of the unitary residential A/C units. The evaporator and tubing sets are factory evacuated and filled with a holding charge of refrigerant. During field assembly when the connectors are made up they automatically open the seal with little or no refrigerant loss. Such connectors are swivel type and are less likely to be mismade than conventional flared or compression fittings, according to the manufacturer. (One manufacturer, however, is of the opinion that conventional fittings, if properly installed under supervision, are as good from a potential leak viewpoint.)

These seal connectors are of two types; one being a seal that is pierced when assembled and does not reseal when broken again. This type is the one used in 40-50 percent of the unitary residential units. The other, that will reseal itself, is more expensive and currently is used only in mobile homes, as protection against untrained mechanics. Such connectors may provide an answer to much of the leakage in other field-assembled units.

Another method that has been suggested to reduce leaks in these systems is that field systems be assembled by silver soldering the majority of connections instead of using the customary tubing connectors. Indeed, according to several representative contractors, they preassembled as much of the tubing as possible so as to have a minimum number of connectors made up in the field. However, it was also reported that field soldering is difficult and probably not practical. This approach may warrant further investigation.

In any event, it appears that the bulk of losses from these systems may come from servicing rather than leakage, where a more common practice apparently is to vent the old charge completely, in smaller units, before adding the new refrigerant and lubricant, on the supposition that water or air or oil residues may be partially the cause of malfunction. On larger units, partial bleed off is practiced for the same reason. This practice and potential solutions to the losses incurred are discussed under "Recovery During Servicing or Disposal" below.

An additional potential leak reduction procedure would be to require use of electronic leak detectors for all field installations. Apparently most manufacturers use these instruments, but the common field test is to use the torch tester that indicates halocarbon presence by a color change of the flame: its sensitivity is 3.2 oz/year compared to 0.01 oz/year for the electronic detector. The objection to using the electronic detector has been stated as too high a sensitivity, so that when making up the refrigeration system, there is too much fluorocarbon about and the detector is alarming all the time: the installer can't locate the leak. Also, leakage at installation will remain in the area for some time. These objections are open to question: the less sensitive detector may be used for locating large leaks. If necessary, the installations may be left for a day or so and then rechecked with the electronic detector. Obviously, the cost of installation increases, but the objective of lowest possible leakage is attained.

Recovery During Servicing or Disposal - The largest losses from hermetically sealed units appear to occur upon disposal. Currently there is no incentive for recovery of the refrigerant charge, and since the scrap value of such units is marginal at best, most are discarded in dumps where ultimately loss of the remaining charge occurs.

Disposal losses may be prevented if the right combination of incentives is provided, backed by regulation. A relatively inexpensive pump and receiver tank constitutes the principal capital investment required for a service organization or individual to collect refrigerant for recycle. Since prices for refrigerant run in the order of $2.00 or so per pound retail, and appliance charges are often one pound or less, recovery is an economically marginal activity. Therefore, possible additional incentives may be bounties or rebates, possibly covered by an initial purchase price addition. Such a procedure would probably require a training program for servicemen and centrally located recycling centers for reception and reprocessing of the returned refrigerant.

Prevention of losses from the non-hermetically sealed units may be possible using the same approach of incentive plus regulation. These units are serviced by competent, trained persons who should be able to handle recovery with little additional training.

Of particular interest here is auto air conditioning. As previously stated, the current servicing use appears to be about a pound per year per unit, whereas manufacturers claim the units should not leak more than about two to three ounces per year, and that the remaining replacement use is unwarranted. This area requires more investigation and definition to ascertain whether such use is or is not necessary. If it turns out that such use really is not necessary but the shops think it is, a re-education program may be in order, and, perhaps, diagnostic tools or methods may be developed to assist the shop personnel to establish the real cause of auto air conditioning malfunction. In addition, sale of recharge cans on the open market as a do-it-yourself kit may have to be restricted.

d. Evaluation of Chemical Alternatives

Alternative Refrigerants for Vapor Compression Cycle - The 1972 ASHRAE Handbook of Fundamentals[a] lists 78 refrigerants with standard designation. They are categorized as follows:

Category	Number of Chemicals Listed
Halocarbon Compounds	39
Cyclic Organic Compounds	3
Azeotropes	5
Hydrocarbons	5
Oxygen Compounds	2
Nitrogen Compounds	2
Inorganic Compounds	12
Unsaturated Organic Compounds	10

Particular refrigerants have been selected over the years as the more desirable chemicals from the viewpoint of performance, availability and price. The halocarbons, cyclic organic compounds and azeotropes have largely replaced all the others (compounds R-11, 12 and 22 appear to have dominated) in spite of generally higher prices. The reason this has occurred is the combination of nontoxicity, and chemical inertness along with good performance characteristics inherent in these compounds. In the following discussion, the more common factors used to evaluate refrigerants are discussed.

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[a] Chapter 14 of this volume is an excellent reference on refrigerants.

- Toxicity

Underwriters' Laboratories classify the comparative hazards to life of gases and vapors in six groups ranging from sulfur dioxide (a refrigerant formerly in wide use) which, in concentrations of about one-half to one percent for durations of exposure of about 5 minutes, is lethal or produces serious injury, to Refrigerant 12, which in concentrations up to at least about 20 percent by volume for durations of exposure of about 2 hours does not appear to produce injury. Most of the fluorocarbons fall under the very low toxicity classifications, numbers 5 and 6. Ammonia (another common refrigerant in the past and still used) falls into Group 2, also quite lethal. Even methylene chloride which was suggested as a reasonable substitute refrigerant by one chemical manufacturer interviewed, is listed as just slightly less toxic than Group 4 which is considered lethal at 2 to 2 1/2 percent for two hours' exposure: This could still be a serious hazard for home appliances where people may be sleeping at the time when a leak occurs, although it may be acceptable in large industrial or commercial uses where size may justify the added precautions and equipment needed for protection against accidents.

- Flammability

Flammability is of concern from the viewpoints of the manufacturer who has to handle it, as well as of the user, because of potential leakage. Ammonia leakage in food storage warehouses still causes explosions. Sulfur dioxide is nonflammable but highly toxic. Methylene chloride and the fluorocarbons are nonflammable. The hydrocarbons, such as butane and iso-butane, are good refrigerants, nontoxic but flammable.

- Effect on Elastomers

Since elastomers are used as o-ring seals and gaskets in refrigeration systems, their compatibility with the refrigerant is important to prevent leaks. Further, the combined effects of the refrigerant with the lubricant used in sealed systems is often synergistic. Methylene chloride is quite hard on most common elastomers, as is Refrigerant 21: most other common fluorocarbon refrigerants have at least one or two common elastomers that are little affected but in this category they do not appear to have a clear cut advantage over alternate refrigerants. Hydrocarbons have almost no effect on elastomers.

- Effect on Construction Materials

Ammonia cannot be used with copper-bearing metals. Sulfur dioxide reacts with any moisture present to form sulfuric acid which is very corrosive to most metals. Magnesium, zinc and aluminum alloys containing more than 2 percent magnesium are not recommended for use with the halogenated compounds where even trace amounts of water are present. So again, for most refrigerants, materials of construction must be carefully selected, although again, hydrocarbons are quite non-reactive.

- Performance Characteristics

To quote from the ASHRAE Handbook of Fundamentals: "As a rule, the selection of a refrigerant is a compromise between conflicting desirable properties. For example, the pressure in the evaporator should be as high as possible and, at the same time, a low condensing pressure is desirable. Low viscosity and low surface tension are desirable properties but, on the other hand, they make it difficult to provide dropwise condensation which would improve heat transfer. High capacity accompanied by low power requirements would also be desirable if possible. These and other conflicts must be resolved in selecting a refrigerant.

Since evaporation of the liquid is the only step in the refrigeration cycle which produces cooling, the latent heat of a refrigerant should be as large as possible. On a molar basis the latent heat is about the same for materials having the same boiling point.

Since the compressor operates on volumes of gas or moles, refrigerants with similar boiling points will produce similar capacities in the same compressor. The weight of the refrigerant circulated would be different, depending on the molecular weight. The compression ratio in centrifugal compressors is affected by the vapor density. The density is related to the molecular weight of the gas as well as the temperature and pressure of operation."

As a result of these considerations and others, within reasonable operating pressures the choice of refrigerants are particularly restricted for use as components in multistage systems for achieving low temperatures, and for use in normal "low" temperature refrigerators/freezers, as well as in standard refrigerators, and air conditioners. For these reasons, Refrigerant 12 has only one or two potential substitutes even among the fluorochlorocarbons, for the common household refrigerator, without involving total redesign.

Potential Substitution

• Substitution of Halocarbons

If Refrigerant 22 is an acceptable compound, having a hydrogen bond and, hence, being subject to destruction before becoming a hazard to the ozone layer, then window air conditioning units, unitary air conditioning systems and some central chillers will be unaffected. These applications appear to account for a significant portion of the AC&R applications. Changing from 12 to 22 for the home refrigerators and freezers would require substantial redesign. R-22 is widely used for reciprocating units in central commercial air-conditioning systems, up to about 100 ton capacity, and for centrifugals over 3000 tons or so. The much higher pressure required for R-22 means increased initial cost in terms of wall thickness, welds, code requirements, etc. and is worthwhile in the larger centrifugals. R-11 is used for centrifugals up to 300 tons or so (and operates under a vacuum), and R-12 is used for the intermediate centrifugals. Therefore conversion to R-22 would require complete redesign of the small and intermediate centrifugals up to about 3000 tons capacity.

Changing from 12 to 22 for auto air conditioners would require a considerably more complex redesign than that required for a similar conversion for refrigerators and freezers, primarily caused by the high temperatures the system is exposed to under the hood. In addition to the higher pressures, the higher temperature may cause stability problems for the refrigerant, and will greatly increase the permeation through currently used elastomer flexible hose.

For all the applications described above that potentially could use 22 in place of 12, a severe constraint is placed on the conversion due to the fact that, particularly for home refrigerators and freezers, the high degree of competition and resulting low margin of profit available to the manufacturer, combined with the potential legal responsibility for consumer products under today's laws, may discourage manufacturers to the point of their considering going out of the appliance business and investing the capital in other ventures or in other divisions of the company.

Refrigerant 501 is an azeotropic mixture of 75 percent of Refrigerant 22 and 25 percent Refrigerant 12 and, therefore, is not an acceptable substitute.

If we then consider that R-22 is not acceptable either, further consideration leads to development of equipment to handle perfluorides, or development of a completely new refrigerant. The perfluorides are in the order of 20 times more costly than R-12, since R-12 is an intermediate. Perfluorides also have poor compatibility with the lubricants. In addition, the perfluorides would have to be thoroughly investigated and proven to have no ill effect on the ozone layer, in addition to passing the more conventional requirements, before industry would be willing to undertake both their manufacture and use.

- Ammonia

Ammonia is a very good refrigerant and is used in both the vapor compression cycle and the absorption cycle (to be described later). It is, however, both toxic and flammable. Hence its use has been restricted largely to industrial storage and manufacturing operations where the practices and precautions are able to be enforced to assure safety. For use in commercial buildings and in homes, a major redesign would be required to contain the ammonia cycle equipment out-of-doors where chances of hazards would be minimized, or to take other precautions to ensure personal safety.

Ammonia is closer to R-22 than to R-12 in characteristics that bear on equipment design: hence it would present a severe restriction on design of a substitute system for automotive air conditioning, for the reasons cited in the preceding section of this report: high temperatures under the hood, and high condensing pressures.

- Hydrocarbons

Many of the hydrocarbons are good performers as refrigerants, and are used in industrial environments to some degree. Propane, butane, and iso-butane are three common hydrocarbons that have good refrigeration characteristics and, though flammable, are not toxic. Their use would necessitate adequate safeguards against reaching explosive limits in air mixtures, and probably require mounting the refrigerant cycle equipment outside of areas occupied by people, such as homes.

Alternative Refrigerants for Other Cycles - Although the vapor compression cycle dominates the refrigeration and air conditioning industry, other cycles are used. The most commonly used are: absorption, thermoelectric, steam jet, air cycle and liquid nitrogen.

- Absorption

A simplified diagram of the basic absorption refrigeration cycle is shown in Figure IV-3.

As in the vapor compression cycle, the refrigerant is pressurized, liquefied, cooled and then allowed to vaporize in the evaporator where it absorbs heat to accomplish refrigeration. However, instead of using a compressor to pressurize the refrigerant, it is cooled to permit liquefaction at a low pressure by absorption in a miscible absorbent fluid and pumped as a liquid to the generator. Heat is applied at the generator to drive off the refrigerant as a vapor and to pressurize it. The refrigerant is then cooled in the condenser to form a pressurized liquid for use in the evaporator again.

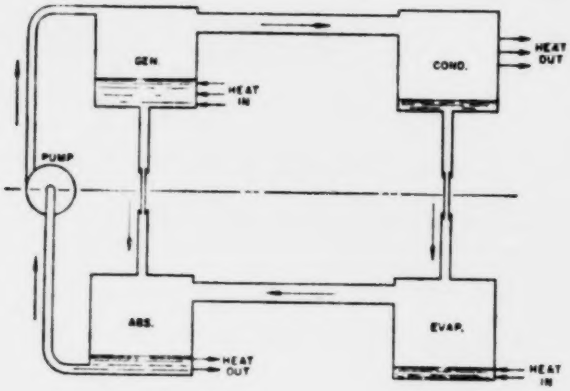
GEN
HEAT
IN
COND.
HEAT
OUT
PUMP
ABS.
HEAT
OUT
EVAP.
HEAT
IN

Figure IV-3. Basic Absorption Refrigeration Cycle

Source: ASHRAE Handbook of Fundamentals, American Society of Heating Refrigeration and Air-Conditioning Engineers, Inc., Joseph D. Pierce, Chairman, 1972.

Modern systems are more complex, mostly due to devices to increase thermal efficiency.

Two systems have been commercialized: water-lithium bromide, and ammonia-water. In the former, water is the refrigerant and a water-lithium bromide solution is the absorber, whereas in the latter, ammonia is the refrigerant and water is the absorber. Because of the toxicity and flammability of ammonia, the water-lithium bromide appears to have gained greater acceptance and is used for commercial air conditioning.

The ASHRAE Handbook of Fundamentals discusses advantages and disadvantages of the various absorption pairs and should be referred to for more detail.

The April 7, 1975, issue of Air Conditioning, Heating and Refrigeration News shows that 2,222 absorption and adsorption units were shipped in 1973. These quantities peaked at 3,193 in 1970 and have declined to the above value.

The water-lithium bromide system is limited to refrigeration above 32°F, however, since the refrigerant freezes at that temperature. As a result, it has been applied principally to commercial air conditioning. Under promotional support by the gas industry, even home air conditioning systems have been made and sold in the past.

It should be noted that substituting the absorption cycle for the vapor compression cycle has implications on the type and quantity of energy use. If electricity must be used, for instance, heat is used at the power generating station to produce electricity, which then is subject to transmission losses, and then is converted into heat again to power the absorption refrigeration system. The net result is very low energy efficiency. On the other hand, moderate temperature waste heat may be used as the energy source for absorption systems. Indeed, as the technology of solar energy is developed, absorption systems will be designed using heat from the sun as at least part of the energy input.

An interesting comparison of the efficiency of power use of absorption and thermoelectric with vapor compression is given in the ASHRAE Guide and Data Book, Equipment, 1972, as follows: "Operating efficiencies of the three most practical refrigeration systems are as follows for a 0°F freezer and 90°F ambient:

- Thermoelectric: approximately 0.3 Btu/Watt hr
- Absorption: approximately 1.5 Btu/Watt hr
- Vapor Compression: approximately 3.0 Btu/Watt hr"

However, conversations with manufacturers indicate that absorption cycles are close to vapor compression systems at their present stage of development: They are more expensive in terms of initial cost but may pay for this difference long term in lower operating costs. Further, units are now available that operate off of hot water as a heat source and are being used in conjunction with solar heating plants.

• Thermoelectric

There was a great flurry of activity ten years or so ago in development work with thermoelectric approaches. This method consists of forcing electrical current to flow through a thermocouple junction (two dissimilar metal wires connected together in a loop) which causes heat absorption. However, although most refrigeration and air conditioning firms tried to develop commercial equipment, all such work appears to have ceased: The approach has been deemed not commercially feasible, primarily due to a high initial cost in the order of ten times conventional refrigeration systems.

Thermoelectric systems efficiencies are an order of magnitude lower than vapor compression systems, as noted in the discussion of absorption systems immediately preceding.

- Air Cycle Refrigeration

Air cycle refrigeration equipment is still used for air conditioning in some aircraft: The "Brayton" cycle offers low weight and compactness over vapor compression cycle equipment. Air cycles were used for cold storage and heater/cooler applications but were displaced from those uses by the advent of halocarbons. They do offer an alternative to halocarbons, using a safe, nontoxic and cheap refrigerant: air. The air cycle equipment has a low efficiency, however, and this fact has restricted its use severely.

- Steam Jet Refrigeration

Steam jet refrigeration systems are used for industrial cooling applications such as freeze-drying foods, chemical crystallizers, etc. In these systems water is the refrigerant and is pumped and compressed by a steam jet ejector instead of a motor-driven compressor. Thus, like the lithium bromide or ammonia absorption systems, the equipment is simple, quiet, low in vibration, and low in cost. However, it must reject two to three times as much heat as a conventional vapor compression type and generally requires water cooling.

- Liquid Nitrogen

Liquid nitrogen is used as a refrigerant for refrigerated trucks and trailers, where a hard freeze is required (and for cryogenic applications). At this point, we do not know how competitive such systems are for broad use, but they are obviously competitive for these specialized applications. Since nitrogen makes up four-fifths of the atmosphere and is nonflammable and nontoxic, it appears to be a good alternate to consider in more depth if fluorocarbon use must be discontinued. The major disadvantages of liquid nitrogen are constant replenishment and the special care required in handling and distribution due to its very low temperature. The low temperature of liquid nitrogen also imposes a very large thermodynamic disadvantage on such a system overall whereas a conventional freezer requires 1.002 HP of work per ton of refrigeration at 32°F, a liquid nitrogen system requires approximately 2.65 HP. This is really a special application which is not practical in most potential uses.

e. Problems with Implementation of Potential Solutions -

Development Time - It must be recognized that the current equipment and refrigerants have been developed after many trials and errors, and that they represent the most economical solutions to refrigeration and air conditioning needs: any changes will involve redesign with associated time and cost commitments.

Potential solutions other than installation and servicing procedure changes may be classified as product modifications and new product development.

- Product Modifications

This category may include such changes as metal hose substitution in auto air conditioning systems, and substitution of self-sealing connectors for field-installed systems.

Development time for such changes may range from a year for testing alternate connectors up to 2 to 2-1/2 years for the design and testing of alternate hose materials and configurations. Another 1 to 2-1/2 years would be needed for tooling and start-up of new production equipment, according to industry sources.

- New Product Development

Examples that fall under this classification may be development of a new refrigerant and/or development of equipment to use the new or an existing alternate refrigerant.

Industry sources have stated the following time requirements:

Refrigerant Producer		Years
Identification of new refrigerant and toxicity tests		2-5
Pilot plant testing		1
New production facility		3
	subtotal	6-9
Equipment Manufacturer		
Design and test		3-5
Limited production field trials		2
Obtain new manufacturing equipment		2
	subtotal	7-9

Thus, according to industry sources, a 7-9 year development period may be required to convert from R-12 to R-22 in those applications where conversion is feasible. Full commercial development of a completely new refrigerant could require a similar time period, although some overlap would be expected.

Development Costs - Even small changes made to high-volume products such as refrigerators and auto air conditioners involve significant capital needs. In particular, the consumer oriented products must be exhaustively tested both to satisfy regulatory agencies and in addition to assure the manufacturer that he will not expose his customers to either hazardous equipment or to an inferior product in a very competitive marketplace. Because of these restrictions the market for such products has dictated evolutionary product development, not a revolutionary one.

The extensive development program is followed by the need for heavy capital investment in tooling for such high-volume products, since the manufacturing lines are highly automated.

f. Cost-Effectiveness of Potential Solutions

Containment and Recovery

Because of the very high development costs, extended development time requirements and large in-service inventory of equipment, coupled with the observations from Table IV-5 that on the order of 85 percent of the current emissions are potentially preventable, containment and recovery of a significant portion of that 85 percent may prove to be the more cost-effective short-term method of all the potential solutions discussed here, to reduce fluorocarbon refrigerant emissions.

Even the containment and recovery approach will require a very careful evaluation and will not be without cost penalties for consumers.

Substitution of R-22 for Other Common Halocarbon Refrigerants

If we assume that R-22 is an acceptable refrigerant, then the next most cost-effective approach (eliminating R-11 and 12) may be:

- Home freezers and refrigerators: attempts to use R-22 have not been successful; further development work will be required.
- Home A/C and commercial A/Chillers: small and large units are now available using R-22; intermediate sizes would be redesigned to use R-22.
- Auto A/C may not be adaptable to R-22. Therefore, the more cost-effective course may be the choice of an alternate refrigeration cycle, such as absorption or the reverse Brayton cycle.
- Further development may allow other applications to use R-22.

Existing units could be recharged with R-11 or 12 if some level of emission were deemed acceptable during the useful life of these units.

Complete Restriction of Common Halocarbon Refrigerants

If we assume that R-22 is not acceptable, a safe and technically well-developed choice may be substitution of the absorption cycle.

- Home freezers and refrigerators: since systems have been designed and sold for this application in the past, they could be updated and substituted. The original designers used natural gas as the energy source; modern commercial A/C applications have been designed to use steam or even hot water as the energy source. However, new designs coupled with solar energy sources, electric power, or home heating systems could be developed. The crux of the problem, however, is (based on contemporary technology) the acceptability of a toxic and flammable refrigerant (ammonia).

- Home A/C and commercial A/C: Commercial A/C units employing absorption cycles are available today. Extension of the range of capacities would be required for commercial designs. For home systems, designs have been commercially produced and could be again; the same problems mentioned above for home freezers and refrigerators exist. However, technologically the switch is reasonable.

- Auto air conditioning: Several other alternatives have been seriously investigated for auto A/C; among them are the absorption cycle and the reverse Brayton cycle.

  The absorption cycle does not look very promising for auto A/C for the following reasons:

  a. The absorption cycle requires a heavy duty cycle to attain an acceptable efficiency; auto A/C operates on a very low duty cycle.

  b. The physical size and weight of current designs that use air cooling are too large.

  c. The absorption cycle is sensitive to the acceleration and vibration of a mobile unit, particularly in designs that do not use pumps but rather depend on thermal convection. However, considerable development work is being done on the absorption cycle for use in conjunction with solar heating systems, so this cycle should be watched closely as a potential alternate for existing auto A/C's and also for other applications.

The reverse Brayton cycle can use air as the refrigerant. Systems using this cycle have been built for aircraft use, and development work is being done currently toward extending its use to other applications. At present, it has a very low coefficient of performance, however, it may provide an acceptable substitute system for auto air conditioning. Considerable development is required.

- Other: The dessicant system looks sufficiently developed to be the most cost-effective alternate for dehumidification needs if R-22 is not acceptable. In addition, this system may provide another alternate to the absorption cycle as a less effective but viable general air conditioning system.

In summary, therefore, the more cost-effective approaches may be as follows:

a. R-22 acceptable: conversion of all systems except auto air-conditioning to R-22.

b. R-22 not acceptable: (1) containment and recovery of losses, (2) conversion to absorption cycle with supplemental development of the Brayton cycle and dessicant systems.

Once again, option b.(1) is by far the lowest cost alternative of the three because it involves the least amount of redesign of current systems.

3. Solvents and Drycleaning

a. Fluorocarbon Solvent Applications and Alternatives - In addition to their thermodynamic advantages of high vapor pressures and low boiling points that make them useful in aerosols, blowing agents, and refrigeration systems, fluorocarbons also have useful solvent properties. This has been discussed briefly under aerosol applications. Other major applications of fluorocarbon solvents are in degreasing and drycleaning; the major compounds used are F-113 and F-11. The major advantages of these solvents are: nonflammability; high vapor pressure resulting in quick drying; low heat of vaporization; low order of toxicity; high density; low surface tension; inertness; purity; and selective solvency compared to chlorinated solvent alternatives. Due to their high cost, fluorocarbon solvents are used where these properties are of paramount importance or result in lower unit costs.

Degreasing - Degreasing applications are generally in high technology areas such as aerospace equipment and electronics. Usually a major concern is the minimizing of residual surface contaminants. In the electronics industry in particular, high surface cleanliness is imperative for the reliable operation of minaturized circuitry and semiconductor devices. Where chlorinated solvents offer similar safety and solvency characteristics, some industry contacts expressed concern over traces of the solvent inhibitor[a] left on the cleaned surfaces; on the other hand, a major supplier of these solvents is of the opinion this problem has been solved in most applications. The major chlorinated solvent alternative in this use is inhibited methyl chloroform (1,1,1-trichloroethane). If the problem of inhibitor residues in semiconductor applications can be overcome by advanced inhibitor formulations, it is very likely that the electronics industry could resolve problems of material incompatibility (vis-a-vis methyl chloroform) within 2-3 years.

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[a] Additives which reduce or eliminate hydrolysis of the solvent.

Drycleaning - Domestic use of fluorocarbons in drycleaning is dominated by Dupont's Valclene formulation of F-113. In Europe, F-11 is a common fluorocarbon solvent. Prime selling points are F-113's high vapor pressure (leading to fast drying cycle times) and low toxicity--both very desirable characteristics in coin-operated machines. The selective solvency of F-113 relative to perchloroethylene also allows the cleaning of specialty items such as furs and leather; these materials are now cleaned with the flammable petroleum solvents. The relatively high cost of Valclene has resulted in a high level of vapor emission control on all Valclene machines. It is doubtful that solvent losses could be reduced much farther than they have been already without excessively high control costs.

b. Chlorocarbon Solvent Applications and Alternatives - As outlined previously, the major applications of chlorinated solvents are in drycleaning, metal degreasing, and paint-stripping (methylene chloride only). The character of emissions from the cleaning applications and the options for emission abatement are outlined below.

Metal Degreasing - Metals soiled with oils, greases, waxes, tars, and other soils not readily removed with water are often cleaned using organic solvents--either common hydrocarbons such as kerosene, methyl ethyl ketone, acetone, mineral spirits, and alcohols; or halogenated hydrocarbons such as as perchlorethylene and trichlorotrifluoroethane (F-113). This type of operation is involved in a wide range of industries, the major category being the metal working industry. This group includes automotive, aircraft, appliance, electronics, and business and industrial machinery manufacturers. Other manufacturing industries such as printing and plastics companies use these solvents in normal maintenance. Similar usage occurs even in nonmanufacturing industries such as automotive and appliance repair stations.

However, most of the smaller non-manufacturing uses of metal cleaning solvents use the less expensive hydrocarbon solvents. It is usually in the larger, more routine manufacturing industries, where fire safety and recovery ability are important factors, that the nonflammable and more expensive halogenated solvents are used.

Metal degreasing can be roughly classified into two types of operation: cold cleaning and vapor degreasing. Cold cleaning involves dissolution and removal of the soil from the work when contacted with liquid solvent by immersion, spraying, or wiping. Vapor degreasing is usually a larger, more centralized operation; a schematic vapor degreaser is illustrated in Figure IV-4. The equipment basically consists of an immersion heater in a liquid sump, a vapor space containing the dense chlorinated solvent vapors, a circumferential freeboard chiller--a network of water cooled and/or refrigerated tubing--that contains the vapor layer, and freeboard wall section that further confines the vapor. The installation also usually possesses a hood or group of lip vents which recover vapors escaping from the degreaser. In operation, the cold, soiled work penetrates the solvent vapor space and condenses a continuous flux of pure solvent on its surface which dissolves and rinses away soil leaving a clean, hot surface which dries almost immediately upon exiting the degreaser. Cleaning may be facilitated by immersion or spray contact with liquid solvent. Larger vapor degreasers are often enclosed and conveyorized and are illustrated in Figure IV-5. Continuous distillation of solvent from the sump concentrates soil in the base of the degreaser raising the boiling point of the sump liquid. When this temperature reaches a certain point, the solvent is distilled first in the degreaser, then in a more efficient still to further concentrate the sludge. Solvent concentration in the ultimate still bottom

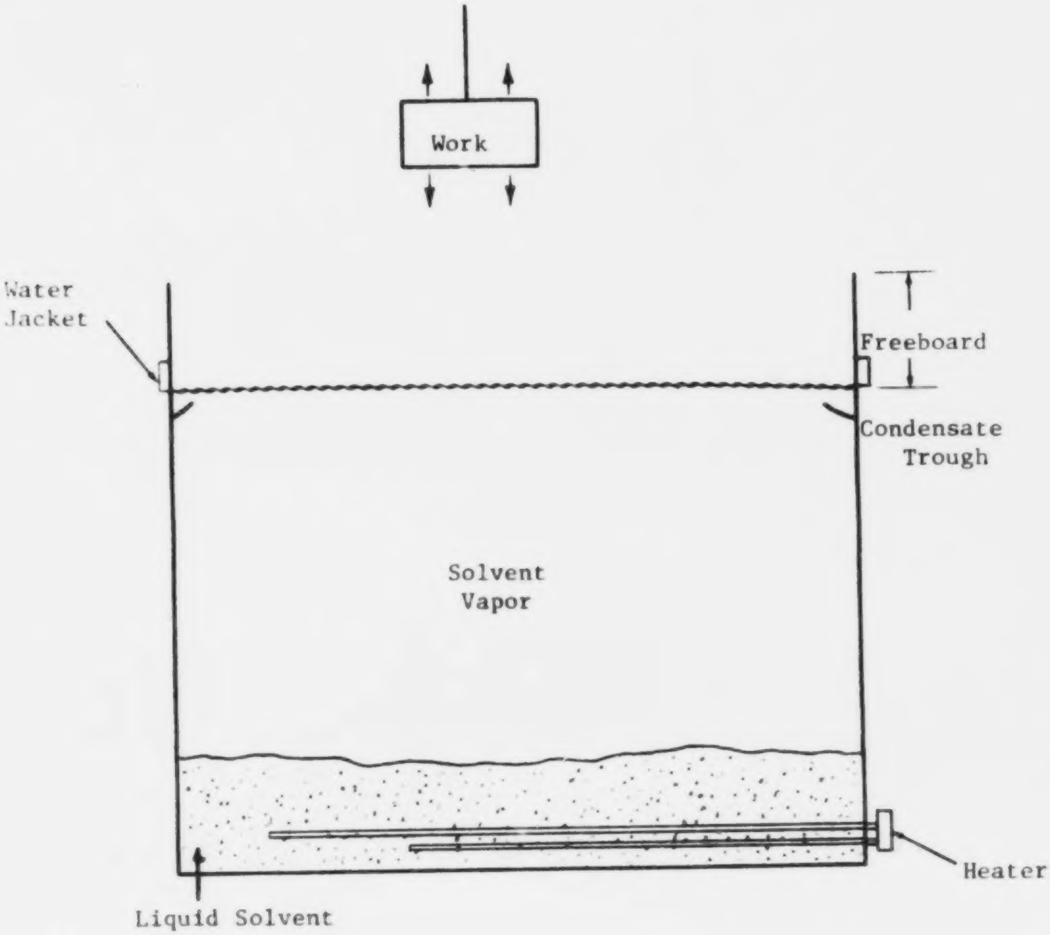
Work
Water Jacket
Freeboard
Condensate Trough
Solvent Vapor
Heater
Liquid Solvent

Figure IV-4. Basic Vapor Degreaser

Source: Arthur D. Little, Inc.

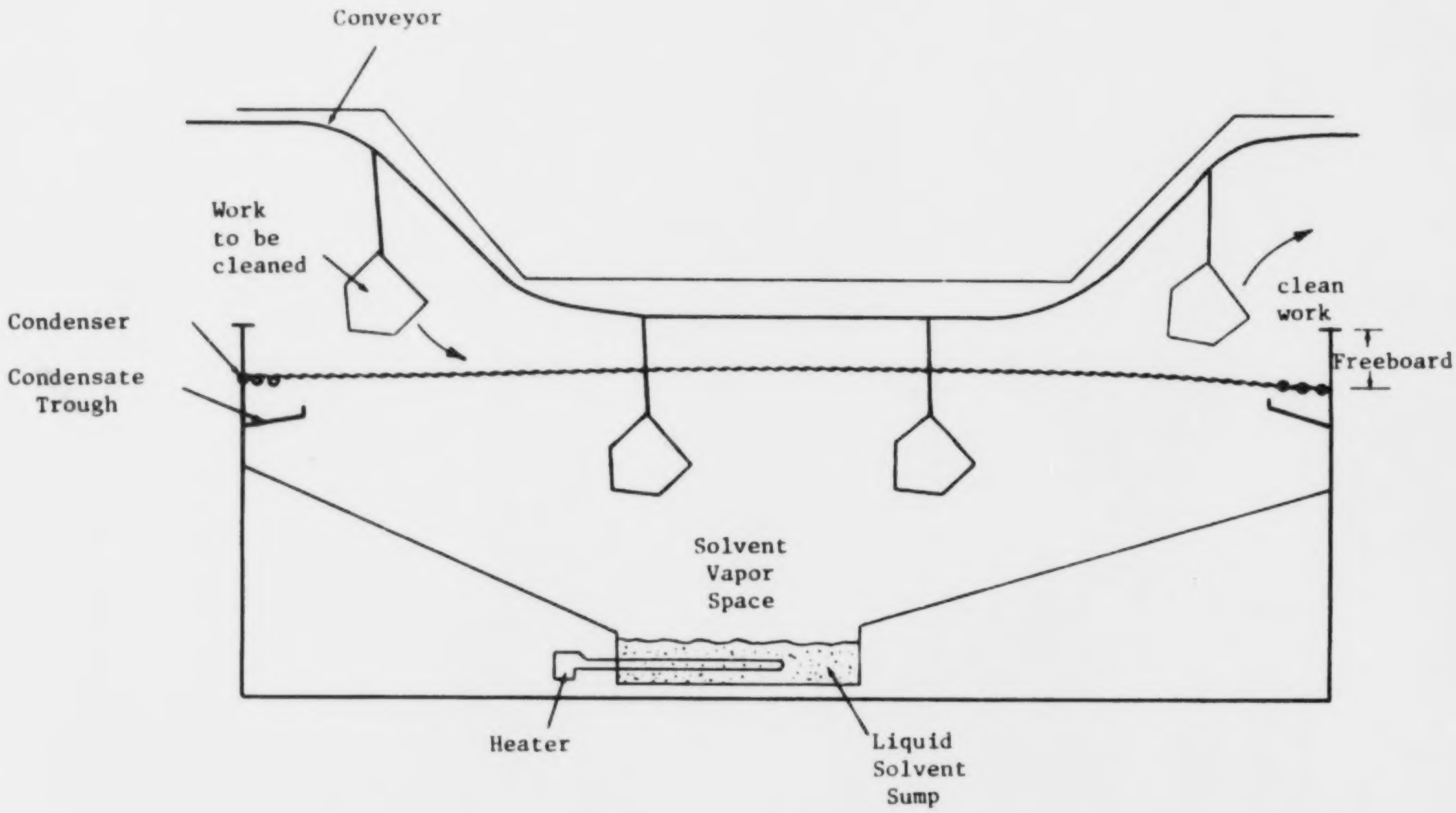
Conveyor
Work
to be
cleaned
Condenser
Condensate
Trough
clean
work
Freeboard
Solvent
Vapor
Space
Heater
Liquid
Solvent
Sump

Figure IV-5. Enclosed Conveyorized Vapor Degreaser

Source: Arthur D. Little, Inc.

residue will range from less than 5 percent to 40 percent by volume. Contaminated cold cleaning solvents are usually recovered in the same way.

Cold cleaning solvent losses are usually difficult to control since the operation is often decentralized, individual stations are often small, and a large part of the loss may be carried off on the work. Vapor degreasers are sometimes referred to as a "controlled" method of solvent cleaning. Losses are localized and usually occur as diffusive or convective vapor loss, dragout of condensed solvent on the work, and sludge losses due to inadequate distillation or steam stripping. Diffusive and convective losses are estimated to be 0.125 to 1.0 lbs/hr per square foot of air-solvent interface depending on the method of operation. Dragout losses are impossible to quantify in a general way, but can be very large if the operation is run incorrectly. Still-bottom losses may represent up to 20 percent of the losses from a well run open-top degreaser, and proportionately more for an enclosed automated line.

Metal degreasers have already come under heavy pressure to control emissions. Their first challenge came from Los Angeles County's Rule 66 and similar legislation which attempted to control trichloroethylene emissions since that compound had been implicated in smog formation. The industry is under growing pressure from OSHA to reduce work area vapor concentrations due to increasingly stringent threshold limit value (TLV) assignments. As a result, many manufacturers have switched from trichloroethylene to another chlorinated solvent, usually a chemically inhibited form of 1,1,1-trichloroethane. There is an understandable and well justified reluctance in industry to move to the flammable petroleum solvents, especially since these often come under the same environmental and health safety regulations. Metal degreasers have also reconsidered alkaline aqueous washes as a substitute for solvent cleaning. Historically, there have been good reasons for using the relatively expensive chlorinated solvents, such as quality of cleaning, metal compatibility, building space constraints, ease of integration in the manufacturing process, overall cost, and water pollution control regulations. In some cases, the cost of solvent emission control may change the relative cost advantage of solvent cleaning vis-a-vis alkaline washing. New chemical formulations have resulted in aqueous washes more compatible with non-ferrous metals and less conducive to rusting or corrosion. Still, it is difficult to make general statements on the economic viability of switching to aqueous washes especially given the rising price of fuels for wash drying ovens, more stringent water pollution control, and site-specific constraints such as available space.

Fortunately, it appears that emissions from solvent degreasers, especially vapor degreasers, can be significantly reduced with control techniques presently available at relatively low cost. There are many vendors now selling auxiliary refrigerated freeboard chillers which can reasonably be expected to reduce present solvent losses by 40 percent at many locations. Commercial carbon adsorption units which have been economically viable only on large systems have also been readily sold which may eliminate losses by 50 percent or more. Sales impetus for these control devices has come both from regulatory requirements and from the economic incentive of recovering valuable solvent. A third control device which could have significant impact on the most common type of degreaser[a]--the simple open-top unit--is a cover which must be down when work is not being done. An alarm or servoactuator could ensure its proper use and the cost would be relatively small. If one assumes a 15 square foot degreaser open for 3 hrs/day with no work being processed, using such a cover would save over $800 per year in solvent worth 15-1/2¢/lb, with a diffusion rate of 0.5 lb/hr ft^2; this payback is more than the estimated cost of the cover.

At many degreasing installations, solvent losses may be considerably reduced by ensuring proper installation, maintenance, and operation. Solvent losses may be very large if concave or closely packed work is not tumbled, shaken, or racked in the degreaser to prevent liquid carry-out. Installation near open windows or improperly positioned ventilation fans or ducts can greatly increase convective losses; excessive exit and entrance speeds through the vapor blanket will also cause undesirable turbulence. Overloading a degreaser with cold work will collapse the vapor blanket; as it is re-established, solvent laden air will be forced from the degreaser. These operating abuses are avoided in large installations by the use of properly designed, enclosed conveyorized units. Such a machine also minimizes the area of the solvent-air interface reducing diffusive losses. Such a complex design may now be more saleable relative to the less expensive and poorer controlled open-top degreaser, if regulations on allowable emissions force a comparison between it and an alkaline wash system.

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[a] This control device would also apply to many cold cleaning systems.

The last important avenue of control is ensuring proper recovery and disposal of contaminated solvent. As previously mentioned, distillation and steam stripping can recover most of the solvent from degreaser wastes. However, such facilities are not always available or properly employed. In such cases, central reprocessing could be required. For combinations of soil and solvent where considerable solvent is unavoidably lost in the liquid wastes, incineration of the unrecovered solvent would be a feasible approach.

Manufacturers of emission control equipment have related the costs of control equipment to the cost of solvent loss as a selling point for that equipment. On a representative 3' x 5' open-top degreaser solvent losses may average 0.5 lb/hr ft^2, or over a 2000 hr. work year, 15,000 lbs/yr worth approximately $2325. A new cover and alarm for this machine might cost $250, and save $300/yr in solvent losses; since the cover usually comes with the machine, perhaps $50 might be needed to install an adequate alarm. Alternatively, a refrigerated freeboard chiller might cost $2000 initially, $150/yr to run, and may save $800/yr in solvent loss. Operating separately, an automatic carbon adsorption unit may cost $9000 initially, $400/yr to runk and may save $1100/yr in solvent. The basic cost of the degreaser alone is on the order of $4200.

Although the numbers quoted above are for one specific case, the general pattern of recovered solvent value recouping the cost of emission control appears to apply to most degreasing applications. Furthermore, requiring some method of control of diffusion losses (by proper initial design and/or installation of emission control equipment), ensuring proper equipment operation, and careful disposal of waste sludges, may reduce solvent emissions from degreasing operations in general by 40-60 percent. A definitive study of this problem is being conducted for EPA by a group at Dow Chemical. The final report should be available by the end of 1975 and will include both commercial information and the results of carefully conducted emission tests which will quantify the loss reductions that can be obtained with available technology.

It should be emphasized that if methylchloroform (1,1,1-trichloroethane) is the only domestic halocarbon solvent that must be controlled, then there exists a wide-variety of alternative halogenated solvents. In many cases trichloroethylene would be a perfectly acceptable substitute were it not for conflicting smog-related air pollution regulations. Perchloroethylene is another possible substitute, although its higher boiling point may cause some material or operating problems. Methylene chloride is another possibility, although it may be too active a solvent for many applications. For applications requiring selective solvency, lack of residue, lower temperatures, or otherwise able to justify a higher-priced cleaning agent, there exists a variety of fluorocarbon based solvents; the major one is F-113.

Drycleaning - Drycleaning is the use of organic solvents to clean textile products of stubborn soils or clean textiles which would be damaged by aqueous laundering or high drying temperatures. The major solvents used domestically are perchloroethylene and the petroleum drycleaning solvents: Stoddard solvent and a solvent mixture known as 140-F. Various chemical and equipment vendors, industry associations, and researchers have estimated that 40 percent to 70 percent of domestic drycleaning is done with perchloroethylene; we estimate the fraction to be 65-70 percent at present and historic trends will enlarge that market share in the future. Of minor importance domestically is Dupont's "Valclene" drycleaning solvent based on F-113. Use of this solvent has been discussed in the previous section on fluorocarbons. European drycleaners use, in addition to the solvents already mentioned, trichloroethylene and F-11. Trichloroethylene tends to bleed dyes from acetate fabrics and is therefore unpopular in this country. Until 1928, gasoline was the major domestic drycleaning solvent; it was then superseded by Stoddard solvent--a less flammable and odorfree petroleum based solvent. An awareness of the fire hazard of petroleum solvents led to the development of less flammable 140-F and the adoption of chlorinated solvents--initially carbon tetrachloride. Carbon tetrachloride in turn has been replaced by less toxic perchloroethylene which is now used in 65-70 percent of domestic drycleaning; the balance is still largely held by the less expensive petroleum solvents. Local zoning restrictions and safety codes have and should continue the trend towards halogenated solvents; we understand that no petroleum solvent based equipment has been made in the last several years although some is still being sold from inventories. Characteristics of cleaning solvents are given in Table IV-6.

Approximately 70 percent of the perchloroethylene used in drycleaning is consumed by commercial establishments as opposed to industrial operations. Commercial drycleaning equipment can be divided into three categories: transfer type, dry-to-dry type, and coin-operated. The transfer type machine, with cleaning capacity typically between 20 and 120 pounds, is the design most prevalent today. Figure IV-6 illustrates schematically the operation of such a unit.

In a transfer machine, the clothes are washed in a recirculating solvent stream; an in-line filter continuously removes impurities from the solvent. After washing for a predetermined length of time, the clothes are spun dry--this process of centrifugally draining excess solvent from the work is known in the trade as "extraction." After extracting the bulk of the solvent, the clothes are removed from the washer-extractor and stripped of most of the remaining solvent in a hot air dryer. Steam-heated air circulates past the tumbling clothes, over a water-cooled condenser, and back to the heater with some fraction bled to an exhaust. Periodically the filter must be replaced with a fresh cartridge or load of powder adsorbent. To recover solvent from the wet filter powder (or "muck") most often generated by commercial drycleaners, the waste is steam heated and vaporized solvent is collected by a water-cooled condenser. Conscientious drycleaners also distill a fraction of their solvent volume to remove soils not adsorbed by their filters.

TABLE IV-6 CHARACTERISTICS OF DRYCLEANING SOLVENTS

Property	140-F	140-F R-66 [a]	Stoddard	Stoddard R-66[a]	Perchloroethylene	F-113
Flash Point (TCC), °F	138.2	143	100	108	non-flammable & non-combustible	non-flammable & non-combustible
Initial Boiling Point, °F	357.8	366	305	316	250	117.6
Dry End Point, °F	396	400	350	356	254	not known
Specific Gravity, @ 60 °F	0.789	0.8063	0.779	0.788	1.623	1.574
Density, lb/gal	6.57	6.604	6.49	6.56	13.55	13.16
Aromatic Content, Vol. %	12.1	7.0	11.6	5.9	0	0
Corrosiveness	None	None	None	None	Slight on metal	none
Heat of Vaporization, Btu/lb	$\sim500^{b}$	$\sim500^{b}$	$\sim500^{b}$	$\sim500^{b}$	90	63
Toxicity (TLV) ppm	200	200	200	200	100	1000
Odor	Mild	Mild	Sweet	Sweet	Like ether	Like CCL_4
Color	Water White	Water white	Water White	Water White	Water White	Water White
Vapor Density (Air=1.00)	1.0	1.0	1.0	1.0	5.8	6.3

[a] This refers to the "old" Los Angeles Rule 66 solvent regulation, which allowed up to 8% aromatic content.

[b] This value can be expected to vary depending as it does on the exact composition of the solvent.

Source: **Preliminary data from EPA report on drycleaning being prepared by TRW, Inc., Environmental Services.**

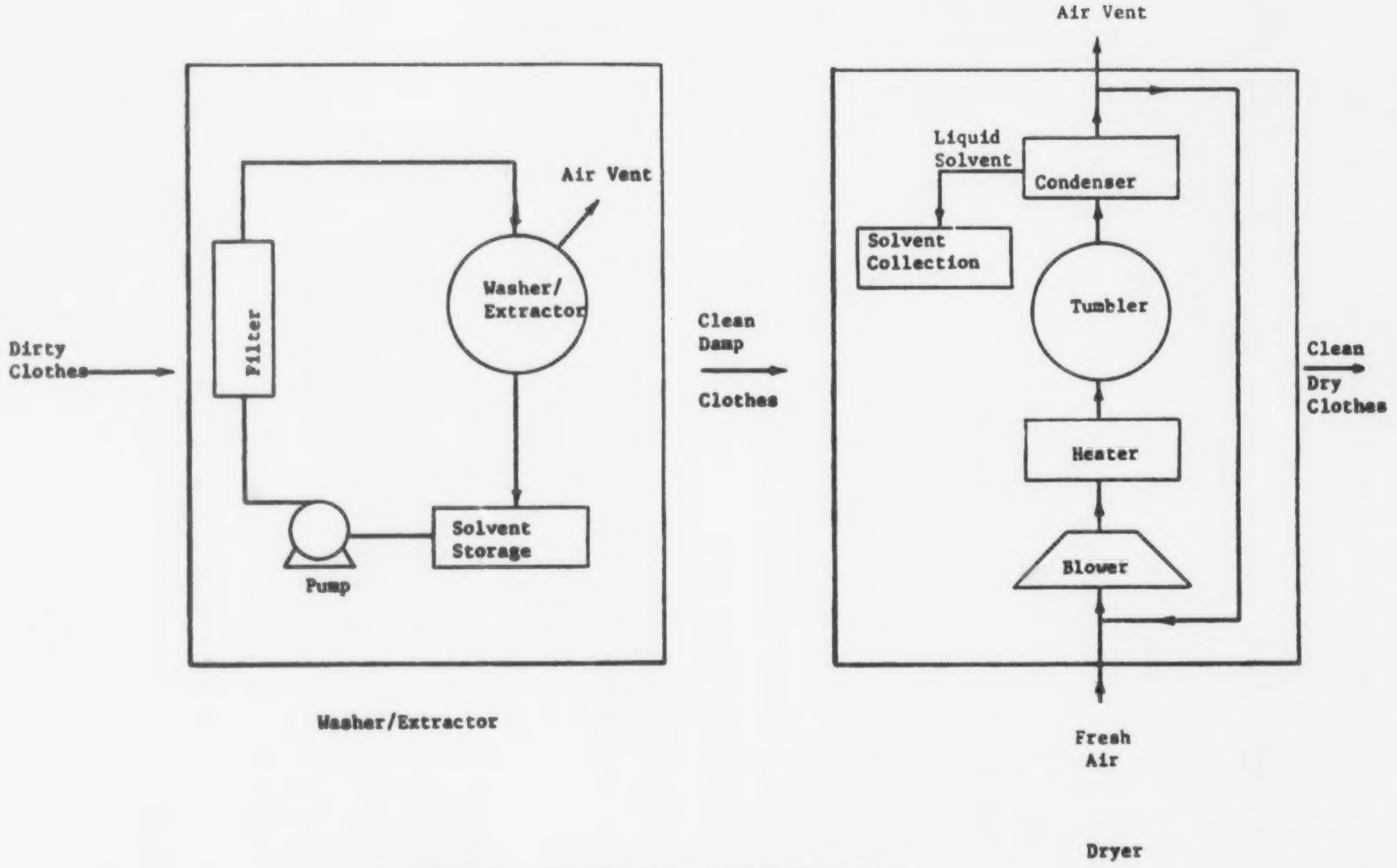
Dirty Clothes
Filter
Washer/ Extractor
Air Vent
Pump
Solvent Storage
Washer/Extractor
Clean Damp Clothes
Air Vent
Liquid Solvent
Condenser
Solvent Collection
Tumbler
Heater
Blower
Clean Dry Clothes
Fresh Air
Dryer

Figure IV-6 Transfer-Type Drycleaning System

Source: Arthur D. Little, Inc.

In the "dry-to-dry" design washing, extraction, and drying all occur in the same machine. This design has the advantages of eliminating the transfer of wet clothes, eliminating a labor consuming operation and providing an opportunity to diminish solvent losses. In practice, many drycleaners feel such a design reduces their throughput and at peak periods they often use the machine just for washing and transfer wet clothes to a separate dryer.

Solvent losses in transfer-type drycleaning operations occur at six points in the system: at the washer-extractor, in transfer to the dryer, at the dryer, as residual solvent in the clothes, in filter wastes, and still bottoms. The amount lost at each point varies widely between installations. Competent operation and maintenance of equipment is a big factor in determining the solvent losses, or the corollary "mileage" obtained in use. The results of a 1975 survey by the International Fabricare Institute have been summarized in a chart (see Figure IV-7) of production efficiency or mileage in terms of pounds of clothes cleaned per drum of solvent.

Solvent loss at the washer can occur because of leaking equipment such as deficient seals, or by convection losses incurred when the door is opened and the system is ventilated. Losses at the dryer can occur for those same reasons and also through pressure-equalizing vent losses, insufficient cooling of the condenser, and inefficient recovery of hot liquid solvent (e.g., collection in open buckets). Filter losses are increased by not draining cartridge type filters or--the more common cause--by inadequate distillation of powdered filter waste sludges. National Institute of Dry-

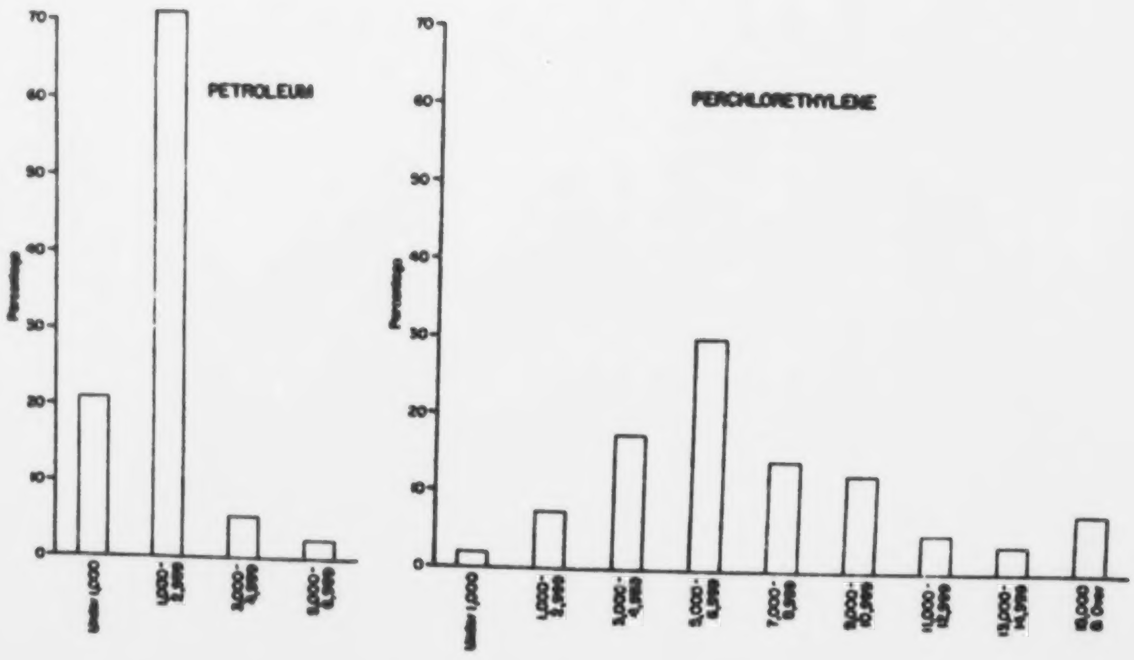

Figure IV-7. Solvent Mileage (in lbs of Clothes Cleaned/55 gal. of Solvent)

Source: "Results of membership survey of drycleaning operations," IFI Special Reporter 3-1 Jan.-Feb. 1975, Published by International Fabricare Institute.

cleaning estimates of filter losses are given in Table IV-7. The same problem of inadequate distillation causes solvent loss in still bottoms; however, distillation is an infrequently practiced technique with most commercial drycleaners so those losses are correspondingly small.

The predominant method of solvent loss control (aside from regular maintenance of good operation) is the use of compact carbon adsorption systems. These units are typically sized to be steam stripped at the end of each day, and, if well maintained, can be expected to pay for themselves within three years in recovered solvent value. The carbon adsorption unit is usually connected with floor vents, and often the washer and dryer ventilation ducts to recover as much of the free solvent vapors as possible. The emission reductions obtainable with these systems are being quantified in a definitive study of drycleaning emission being conducted by a group at TRW for the EPA. The final report of this study should be available by the end of the year.

An interesting perspective on the possibilities for emission reduction is provided by considering the use of F-113 in drycleaning. This solvent is far more expensive than perchloroethylene, and thus high loss rates cannot be economically tolerated. As a result, solvent mileage in Valclene[a] (F-113) machines is typically 30,000 lbs/drum versus 6,900 pounds per drum for most perchloroethylene installations. Valclene is very volatile so losses from equipment could be very high unless good control systems were provided. These units are typically on total recycle of both solvent and air. Pressure equalization is often provided by elastomeric expansion chambers. Solvent recovery in the dryer is enhanced by a refrigerated condenser.

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[a] Registered trademark for DuPont's formulation of F-113 dry cleaning fluid.

Table IV-7. SOLVENT LOSSES IN PERCHLOROETHYLENE PLANTS

(in pounds of perc per 1000 pounds of cleaning)

Point of loss	Plants without vapor adsorber	Plants with vapor adsorber
1. Retained in filter muck:		
(a) Rigid tube filter - no cooker	125	125
(b) Rigid tube filter - muck cooked	45	45
(c) Regenerative filter - muck cooked	20	20
2. Retained in paper cartridges:		
(a) Drained	18	18
(b) Dried in cabinet vented to adsorber	--	12
3. Retained in still residue	16	16

Source: Martin, A.R. and Fred Loibl, "Perc Vapor Emission - How to Estimate It", The NID Technical Bulletin, T-471. May, 1971. National Institute of Drycleaning.

Carbon adsorption is normally provided. If these same measures were applied to perchloroethylene units, the solvent mileage should be as low or lower than that obtained with Valclene due to perchloroethylene's lower volatility. However, there is a penalty for such good control; Valclene units generally cost 25 percent more than comparable perchloroethylene machines equipped with carbon adsorption units.

The cost of solvent in proportion to the other costs of a typical commercial drycleaner is only a small fraction of the total (less than 10%). However, a potentially significant cost may be fines imposed for not complying with OSHA regulations on maximum allowable vapor concentrations.

A number of drycleaning plants now operating do not meet these TLV criteria; as these installations come into compliance, per unit solvent consumption by the industry may decrease since some measures that control ambient vapor concentrations also reduce total solvent loss.

The drycleaning industry will be hard pressed to meet the demands of OSHA and the EPA. Operation of their equipment is traditionally poor as indicated by the average solvent mileage. The industry is experiencing hard times and is short of cash for new investments, even for such remunerative investments as carbon adsorption units. Equipment sales to the industry have plummeted in the last several years. There is a glut of old, used, cheap equipment on the market. Emission control will be just one more burden the industry will find hard to bear.

In summation, it appears that with reasonable care and attention, most drycleaners can reduce their solvent losses by about 50 percent through achieving the solvent mileage performance now reached by only 10 percent of the industry. Emission rates could conceivably be cut to 20 percent of their present level if Valclene emission control technology were adapted to perchloroethylene units at the expense of higher capital and operating costs. In the event that one or both of these solvents had to be eliminated, Valclene could substitute for perchloroethylene in all applications and the reverse substitution could occur in all applications except where the aggressive solvency of perchloroethylene would forbid its use (e.g., in leather cleaning). The petroleum solvents can achieve the same cleaning results as either of these; however, the associated fire hazard would be a serious impediment to reversion to the older technology--both because of existing fire regulations and industry experience. These solvents also have other environmental problems relating to photochemical smog formation.

4. Foam Blowing Agents - Halocarbons are used in the manufacture of foams made from polyurethane, polystyrene, and polyolefins. They are primarily used as the blowing agent which forms the cellular structure. The use of halocarbons as blowing agents in polyolefin foam manufacture is quite small in comparison to their use in polyurethane and polystyrene foams. The most commonly used halocarbons are trichlorofluoromethane (F-11) which is the agent primarily used for polyurethane foam manufacture, and dichlorodifluoromethane (F-12) which is used for both polyurethane and polystyrene foams. Methylene chloride is used to a minor extent in the manufacture of flexible polyurethane foams as a blowing agent but it also finds use as a cleaning solvent in the manufacture of polyurethanes.

a. Plastic Foam Types - The most important foam categories which use halocarbon blowing agents are rigid polyurethane, flexible polyurethane, extruded polystyrene, and expanded polystyrene.

The use of halocarbons in plastic foam manufacture is summarized in Table IV-8.

Rigid polyurethane foam - This is a major application for halocarbon

Table IV-8. DESCRIPTION OF USE OF HALOCARBONS IN PLASTIC FOAM MANUFACTURE

Halocarbon typically used	Type of plastic foam	Type of fabrication process	Location of fabrication process	Typical product application	Alternative blowing agent
F-11,12,113, 114	Low density rigid polyurethane	Pour (bun process) spray in place frothing	Plant, on-site	Insulation	Water/CO_2
F-11	High density rigid polyurethane	Pour	Plant	Furniture parts	Water/CO_2
F-11 Methylene chloride[a]	Flexible polyurethane	Pour	Plant (slab stock or molded shapes)	Cushioning, bonded foam fabrics	Water/CO_2
F-12, Methyl chloride	Extruded polystyrene	Extrusion	Plant	Food trays	Pentane
F-11,12	EPS (expanded polystyrene)	Steam chest molding	Plant	Packaging, insulation	Pentane
F-114,12	Poly olefin	Extrusion	Plant	Packaging, insulation	azodicarbamide aliphatic hydrocarbons nitrogen
Methyl chloride fluorocarbon	Extruded polystyrene board	Extrusion	Plant	Insulation	methylene chloride/ hydrocarbons

[a] Also used as cleaning solvent in urethane foam operation

Source: Arthur D. Little, Inc., estimates based on trade publications and industry contacts.

blowing agents. F-11 is the blowing agent most frequently used. The rigid polyurethane foams are used primarily for insulation. Typical densities of these foams are about 2 pounds per cubic foot. They are either fabricated in-plant (using the "bun" or continuous slab process described below) or on-site using spray techniques.

Minor quantities of rigid polyurethane foams are also made for special applications by the frothing process which uses F-12, F-113 (1,1,2 - trichloro-1,2,2,-trifluoroethane) and F-114 (sym-dichlorotetrafluoroethane.

Another minor application for somewhat higher density rigid polyurethane foams (8 to 30 pounds per cubic foot) is in the fabrication of furniture parts. In this application, the halocarbon blowing agents are less frequently used than alternative blowing agent systems.

For the sake of clarity, we have included all these alternative fabrication methods in the rigid polyurethane foam category. The major component in this category (roughly 80%) are the 2 pounds per cubic foot insulation foams.

Flexible polyurethane foam - The flexible polyurethane foams are primarily used for cushioning and carpet underlay applications. The blowing agent used for flexible polyurethane foam can be either of several fluorocarbons (although F-11 is the most widely used) or to a minor extent methylene chloride. The halocarbon blowing agents are primarily used as a supplement to water/CO_2 blowing agent systems.

Extruded polystyrene foams - Extruded polystyrene sheet, film and board stock use halocarbon blowing agents. Extruded sheet products, which represent the major portion of this category, use F-12 as the principle blowing agent.

Hydrocarbon blowing agents, such as n-pentane, were traditionally used for extruded foam sheet products. Due primarily to fire hazards associated with the manufacturing process, there has, since 1967, been a shift toward the use of halocarbon blowing agents for the manufacture of these products. Rigid extruded board stock uses either methyl chloride or fluorocarbon blowing agents. Densities of these products are typically in the 2-7 pounds per cubic foot range. (Higher density extruded foams are also made for wood substitutes but these typically use solid rather than gaseous or liquid chemical blowing agents.)

Extruded foam sheet is used primarily for disposable dinnerware and packaging applications. Rigid polystyrene board stock is used for packaging and insulation applications.

Expanded polystyrene foam - The term "expanded polystyrene" (EPS) usually refers to a 1-4 pounds per cubic foot foam used for such products as hot drink cups, flotation block, ice-chests, and packaging material. It is made by a molding process (rather than by extrusion). The major blowing agent used for EPS foam manufacture is n-pentane or isopentane but F-11 is being used to an increasing extent.

Polyolefins - Polyolefin foams include both polyethylene and polypropylene although polyethylene is much more frequently used. The low density polyethylene foams were first introduced by the Dow Chemical Company in 1958. They are used in considerably smaller quantities than the polyurethanes and polystyrene foams because the processing methods are somewhat more expensive.

There are two broad categories of polyolefin foams. The low density foams (less than 10 pounds per cubic foot) are made by an extrusion process and the products are sold as sheet, board, and profiles. Both F-114 and F-12 are used as blowing agents. The high density polyolefin foams do not use halocarbon blowing agents.

Typical applications for the low density polyolefin foams are package cushioning, gasketing and sealing, marine buoyancy products, and expansion joints in building construction.

b. Processes for Foam Manufacture - Manufacturing processes for the four major foam types are discussed below.

Rigid and flexible polyurethane foams - Both rigid and flexible polyurethane foams are formed by mixing two or more reactive liquid ingredients together. The chemical reaction which results forms a polymeric structure. The incorporation of a blowing agent (or gas evolved from the polymerization) provides the cellular structure. The ingredients are mixed in a foam machine which consists of a pumping unit capable of accurately metering two or more components and a continuous mixer capable of blending and efficiently mixing the various components. Both the pumping and mixing functions are critical to the proper manufacture of polyurethane foams. The equipment used for mixing and dispensing both rigid and flexible films is quite similar. After dispensing from the metering unit, the physical means used to contain the foaming mixture differs widely.

Rigid polyurethane foams can be manufactured by a batch process, by a continuous slab or "bun" process, by foaming or frothing in place, and by spraying. Of these methods, continuous slab production and foaming in place are the most common. Continuous production of rigid foam slab stock (commonly used for insulation) involves pouring the liquid mixture as a thin layer onto a continuously moving conveyor where it foams to form a continuous block of foam. After oven curing, the foam is sliced to specific thicknesses by a variety of mechanical methods. Occasionally facing materials used as surface skins are continuously applied to rigid foams during fabrication by the continuous slab process. Foaming in place involves pouring the liquid mixture of foam components after mixing directly into a cavity (such as the walls of a refrigerator or building). After chemical reaction, the foam expands to completely fill the cavity. Occasionally a frothing procedure is used in foaming in-place applications. In this procedure, a high pressure mixture is utilized and frothing occurs as the blowing agent (typically F-113 or 114) contained in the foam mixture vaporizes on emerging from the dispenser due to the reduction in pressure.

Sprayed polyurethane foams are often used for on-site application of rigid polyurethane foams. Here the liquid ingredients emerge from the dispenser as a spray rather than a continuous stream. Consequently the losses of halocarbon blowing agent during foam formation are somewhat higher than for the other rigid foaming methods.

Flexible polyurethane foams are made by either a molding process to form such items as automotive safety pads, sun visors, and cushions, or a continuous slab ("bun") process which resembles the continuous slab process used for rigid foams. Conveyors range from 50-100 feet in length. After forming the slabs are cured with radiant heat or steam.

The majority of flexible polyurethane foams are formulated so that an open-celled structure results. In some portion of the cases, they are put through a wringer-like device to crush a portion of the cell walls in order to form an open cell structure which enhances "breathability" of the foams for cushioning applications.

Carbon dioxide, formed by the chemical reaction of water with the isocyanate component of the liquid mixture, is the most commonly used blowing agent for flexible polyurethane foams. Halocarbons are used alone or in combination with the water/CO_2 blowing agent system to produce foams with more desirable physical properties (such as lower density and softer "feel").

Methylene chloride is used to some extent as a blowing agent in flexible foam fabrication. It is also widely used throughout the polyurethane foam industry as a cleaning solvent for flushing foam heads and for general equipment cleanup. It is also used as a thinner to reduce the viscosity of unreacted urethane prepolymer components and in operations which bond flexible polyurethane foams to fabric. Its high volatility causes it to be removed from the foam during heat curing.

Extruded polystyrene - The raw materials for manufacture of extruded polystyrene foams are polystyrene pellets and blowing agent. The polystyrene pellets are fed to the extruder which consists essentially of a screw in a heated barrel. The extruder melts and plasticizes the pellets into a molten mass. The blowing agent is introdueed into a mixing zone along the screw of the extruder. A typical blowing agent injection system is shown in Figure IV-8. The mixture of molten polystyrene resin and dissolved gas is then passed into a second extruder whose function is to reduce the temperature of the mixture and finally extrude it into the

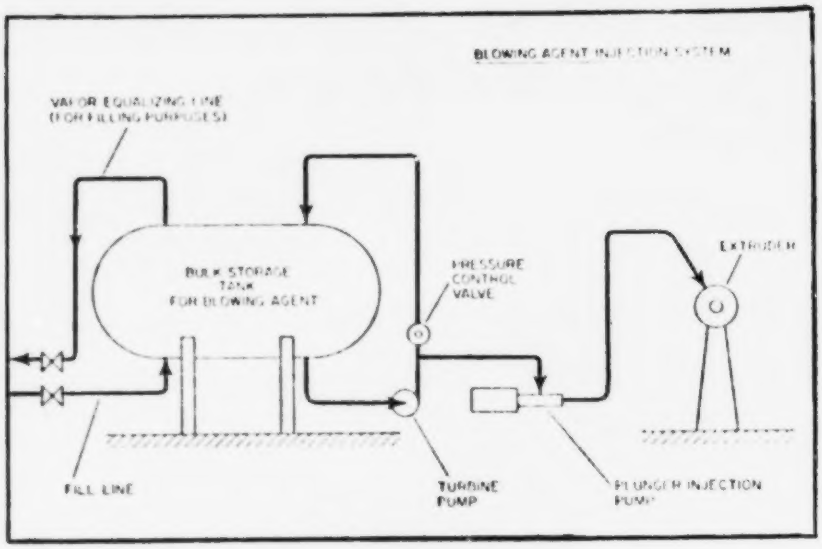
BLOWING AGENT INJECTION SYSTEM
VAPOR EQUALIZING LINE
(FOR FILLING PURPOSES)
BULK STORAGE
TANK
FOR BLOWING AGENT
PRESSURE
CONTROL
VALVE
EXTRUDER
FILL LINE
TURBINE
PUMP
PLUNGER INJECTION
PUMP

Figure IV-8. Schematic Diagram of System Used for Injecting Blowing Agent into Extruder for Production of Foamed Polystyrene Sheet

Source: Plastics Technology, October, 1969, P. 46.

shape of a hollow tube into the atmosphere over a cone shaped expansion die. Cell formation is completed within the walls of this hollow tube. The cooled tube is then slit to specific widths and taken up on large diameter rolls which are stored for several days to permit air to diffuse into the cells. Most of the release of blowing agent occurs at the plant site.

To fabricate the most common products made from extruded polystyrene foam, meat trays and egg cartons, the sheet is heated between two banks of radiant heaters to a semi-molten state and then formed into the shape of the final product in male or female molds using vacuum.

Extruded polystyrene board was originally developed by the Dow Chemical Company. This product, known as Styrofoam® was introduced for military applications during World War II and was used for commercial insulation and floral foam applications thereafter. Typical densities are 1.7 pounds per cubic foot.

Early patents[a] describe the foam board extrusion equipment as a holding vessel with a bottom port and a conveyor with internal mixing to prevent channeling. The mixture is discharged into a tunnel through which the foam expands and is shaped.

Expandable polystyrene (EPS) - Typical applications for EPS foams are for insulation board for the construction industry, flotation block, packaging dunnage, and thread spools. The products typically have densities ranging from 1-4 lbs/cu.ft.

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[a] McIntire, O.R. (to Dow Chemical) U.S. Patent 2,450,436 (1948), and 2,515,250 (1950).

These products are made from an EPS bead which has a density of approximately 40 pcf and contains 5.5-7.5% of a volatile blowing agent. Expansion is carried out by feeding beads to a pre-expander into which controlled live steam is also fed. The pre-expander is a simple insulated cylindrical drum having an agitator to the vertical axis and a discharge chute near the top. It may range anywhere in size from 10-200 gallons, depending on the article to be made. Beads are also expanded by a combination of heat and vacuum. After pre-expansion, the beads are conditioned by passing through an air conveyor to bins or bags where surface moisture evaporates and the internal/external pressure differential due to the blowing agent normalizes, the beads cool and harden, and are then stored for between 24-36 hours.

In molding the beads to their final shape, they are charged to a mold using either air or gravity and the mold is clamped shut. Steam is directly injected into the steam chest surrounding the beads and causes them to expand, fill the interstices between the beads, and finally to fuse or weld together. The mold is then cooled by spraying atomized water or by exhausting using a vacuum pump or jet eductor. Cycle times vary between 6 seconds and 4 minutes, depending on the shape and wall thickness. Six seconds might be a typical time for molded cups; thicker parts used for insulating blocks, for example, might have cycle times of up to 4 minutes.

The blowing agent is incorporated into the beads either by a steeping process or during the suspension polymerization process.

As indicated previously, pentane is the blowing agent most commonly used but recently expandable beads containing F-11 have become commercially available and are used to a minor extent.

Polyolefins - The low density foams are primarily made by an extrusion process similar to that used for extruded polystyrene foams. Plastic pellets are fed to an extruder and the blowing agent (typically F-114 or F-12) is injected along a low pressure section of the extruder screw. The molten polymer and thoroughly dispersed blowing agent are then extruded to the atmosphere via a die of appropriate shape. Expansion (cell formation) takes place and a cell structure is formed. Most of the blowing agent leaves the polymer during this step.

c. Emissions to the Atmosphere - The quantity of halocarbon lost to the atmosphere during manufacture, subsequent field use, and ultimate disposal of plastic foams varies greatly. Listed below are some of the factors which must be considered:

- Type of foam and blowing agent,
- Open versus closed cell content,
- Solubility of halocarbon in the plastic,
- Density and cell structure of the foam,
- Surface area-to-volume ratio of the fabricated foam product,
- Losses during manufacture (highly dependent upon manufacturing process), and
- Rate of diffusion of specific halocarbons through the plastic matrix, highly dependent on whether or not the foam is enclosed during field use.

- Ultimate disposal method and lifetime of the fabricated foam product.

Our estimate of halocarbon losses to the atmosphere from plastic foams is shown in Table IV-9. We have considered the factors listed above and have relied on technical publications, industry contacts as well as our in-house knowledge of the manufacture, field application and ultimate disposal of plastic foams.

The figures shown in Table IV-9 should be regarded as rough estimates. Since it was necessary to include a variety of foam applications into broad categories, product lifetime is highly variable and ultimate disposal methods differ widely. Our general method of estimating losses of halocarbons to the atmosphere from plastic foams is described below. The column numbers refer to Table IV-9.

- In Column 1 we have listed the total quantity of foam used based on estimates of 1973 foam production.
- Column 2 lists our estimate of the percentage of that total foam quantity which uses halocarbons. This percentage was applied to the total in order to derive the total weight of foam using halocarbons shown in Column 3.
- Column 5 is an estimate of the total quantity of halocarbon used, based on the percentage of halocarbon commonly used in manufacturing foams, as shown in Column 4.
- In Column 6 we have estimated the percentage of halocarbon which is lost to the atmosphere during manufacture, field use, and ultimate disposal.

Table IV-9. ESTIMATED U.S. USE OF HALOCARBONS IN PLASTIC FOAM MANUFACTURE - 1973

(millions of pounds)

Type of plastic foam	Halocarbons primarily used	(1) Total quantity of foam produced	(2) Est. percent using halocarbons	(3) Weight of foam using halocarbon blowing agent	(4) Percent of halocarbon commonly used in formulation	(5) Quantity of halocarbon used	(6) Est. percent of halocarbon lost to the atmosphere[a]	(7) Est. quantity of halocarbon lost to atmosphere[a]
Rigid polyurethane	F-11,12 frothing	350	85	300	15	44.8	20	9.0
Flexible polyurethane	F-11,113 mixture methylene chloride[b]	960	55	530	7	35.4	95	32.9
Extruded polystyrene sheet	F-12	140	50	70	7	4.9	95	4.7
Expanded polystyrene (EPS)	F-12	190	5	10	6	0.5	90	0.4
Extruded polystyrene board	Methyl chloride fluorocarbon	35	100	35	10	3.5	100	3.5
Polyolefin	F-114,12	11	65	7	16	1.1	95	1.1
Total		1686	-	952	-	88	-	51

[a] Although almost all of these emissions occur immediately, figure given is for emissions within ten years.

[b] Methylene chloride used both as blowing agent and as solvent.

Source: Modern Plastics, January, 1975, and Arthur D. Little, Inc., estimates.

All of the halocarbon will eventually be lost to the atmosphere. If the foam product is ultimately disposed of by incineration, the halocarbons will be destroyed before leaving the incinerator. In estimating the atmospheric losses shown in Column 6, we have arbitrarily set a 10-year time limit. The estimated total quantity of halocarbon lost to the atmosphere within 10 years is shown in Column 7 and is based on multiplying the estimated percentage halocarbon loss (shown in Column 6) by the quantity of halocarbon used (shown in Column 5).

In Table IV-10 we have prepared an estimate of specific halocarbon losses to the atmosphere (within a 10-year period) based on 1973 production figures. Probably 90 percent of the losses occur during manufacture and the first year thereafter.

Rigid polyurethane foams - It is important to the manufacture of rigid polyurethane foams to minimize losses of blowing agent since the presence of blowing agent in foam insulation is critical to maintaining the low heat transfer coefficient which is a major asset of the rigid polyurethane insulation foams.

Detailed studies[a] have been carried out to predict the diffusion of halocarbon from rigid polyurethane foams, and to predict the concentration of halocarbon remaining in the foam cells. These studies have shown that the rate of diffusion of halocarbon out of the foam is smaller than the rate of diffusion of oxygen and nitrogen into the cells. Other important factors affecting loss of halocarbons to the atmosphere are: ambient temperature during use; surface area to volume ratio of the foam

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[a] Cuddihy, E.F. and J. Moacanin, Cellular Plastics, pub. no. 1462, National Academy of Science (1967).

Table IV-10. ESTIMATED U.S. FLUOROCARBON AND CHLOROCARBON EMISSIONS FROM FOAM BLOWING
(based on 1973 production)

Type of plastic foam	Estimated total quantity of halocarbon lost to atmosphere within 10 years (millions of pounds)	Type of halocarbon typically used	Estimated percentage distribution	Estimated quantities of halocarbon lost to atmosphere (million of pounds)
Rigid polyurethane	9.5	F-11	90	8.6
		F-12,113, 114 - frothing	10	0.9
Flexible polyurethane	32.9	F-11,113	70	22.9
		methylene chloride	30	10.0
Extruded polystyrene sheet	4.6	F-12	100	4.6
Expanded polystyrene (EPS)	0.5	F-12	100	0.5
Extruded polystyrene board	3.5	methyl chloride fluorocarbon	NA	<3.5
Polyolefin	1.1	F-114	60	0.7
		F-12	40	0.4
Total	52.1	-	-	52.1

Source: Arthur D. Little, Inc., estimates.

product; and the extent to which the foam surfaces are exposed to ambient conditions. Norton[a] has studied the fraction of FC-11 which remains in the cells of 1" thick slabs of a 2.2 pcf rigid polyurethane foam aged in air 25°C with both surfaces exposed for time periods from 50 days to 20 years. There is, of course, a distribution of F-11 concentration through the thickness of the foam. Cells at the outer edges lose F-11 very quickly, but after 20 years roughly 12 percent of the original FC-11 still remains in the cells in the center of the foam. In our estimate shown in Column 6 of Table IV-9, we have assumed that the combination of manufacturing, field use, and disposal losses during the initial 10-year life of an average rigid polyurethane foam product are no greater than 20 percent.

Flexible polyurethane foams - We estimate that halocarbons are used in the manufacture of roughly 54 percent of all flexible foams. (Roughly 50 percent of flexible slab foam production and 65 percent of flexible molded foam production use halocarbon blowing agents. The ratio of slab to molded foam production is roughly 3/1.)

Unlike rigid foams, the presence of open cells is critical to the applications for which flexible polyurethanes are used (cushioning and carpet underlay are examples). This results in rapid loss of halocarbon from the interior of the cells. The major portion of halocarbon loss occurs during manufacture or shortly thereafter. Furthermore, the flexible polyurethane foams are more exposed to ambient conditions during field use and on the average probably have a shorter product lifetime than typical rigid polyurethane foam products. We estimate that 95 percent of the halocarbon used to make flexible foams escapes to the atmosphere within 10 years.

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[a] Norton, F.J., Journal of Cellular Plastics, January, 1967, P. 23.

Extruded polystyrene foams - Roughly 50 percent of extruded polystyrene foam sheet production utilizes halocarbon blowing agents. Roughly 85 percent of the blowing agent is lost during manufacture and we estimate that another 10 percent is lost during field use. Thus, essentially all (95 percent) of this halocarbon is lost to the atmosphere within 10 years. It is important to note that there is an increasing trend toward the substitution of halocarbon blowing agents for pentane which in the past was commonly used for extruded foam sheet. The percentage of all extruded polystyrene foam which uses halocarbon blowing agents will probably increase over the next several years.

Expanded polystyrene - Only a small percentage of EPS foam currently uses halocarbon blowing agents; however, we estimate that 90 percent of this quantity is lost to the atmosphere within 10 years.

Extruded polystyrene board - Dow's Styrofoam is the only domestic extruded polystyrene foam board. They consider the identification and concentration of blowing agents to be proprietary information. It is known, however, that fluorocarbons are used as blowing agents in addition to or in combination with methyl chloride. The exact quantity and type of fluorocarbon are not known. We estimate that the weight of blowing agent is less than 10 percent of the weight of Styrofoam production.

d. Alternatives to the Use of Halocarbons

Rigid polyurethane foams - The presence of residual halocarbon within the interior of the cells in rigid polyurethane foam results in a heat transmission rate which is roughly one-half of that which would be experienced if the cells were filled with air. This fact is of primary importance in the use of halocarbon blowing agents for polyurethane manufacture. These materials can be manufactured using the water/CO_2 blowing agent system but the rigid polyurethane foams would then lose their economic advantage over other insulating systems. We are not aware of any satisfactory substitute for halocarbon blowing agents for rigid polyurethane foams which will produce a foam of adequate structural and thermal properties.

Flexible polyurethanes - The halocarbons are primarily used as auxiliary blowing agents in the formation of flexible polyurethane foams. The carbon dioxide which results from the interaction between water and the isocyanate component of the active mixture is the primary blowing agent in most commercially manufactured flexible foams. The use of auxiliary blowing agents allows foams with lower density and lower compression loads to be made than those which are made using the water/CO_2 system alone.

Vacuum blowing has been proposed as a method for eliminating blowing agents in flexible foam production. It is also possible to utilize inert gases as blowing agents. Aroyl azides which decompose to give nitrogen have also been investigated as well as acetic acid and combinations of alcohols and strong acids. Thus, there are a variety of agents which can be substituted for the halocarbons which are used as auxiliary blowing agents in flexible foam manufacture. The use of these agents will undoubtedly result in either an economical or technical compromise when compared to the current halocarbons.

Extruded polystyrene foams - As previously discussed, members of the pentane family (n-pentane, isopentane or petroleum ether) have traditionally been used as blowing agents for extruded polystyrene foams. The advantage of the pentanes is their low cost (roughly one-sixth that of halocarbon blowing agents). The major advantage of the halocarbon blowing agents is their lack of flammability and the ability to produce foam of somewhat lower density than the pentanes. The lower cost of the pentane blowing agents are offset by the necessity for higher capital investment in order to provide explosion and fire protection. Inert gases, such as nitrogen and solid chemical blowing agents are also used to foam polystyrene but their use is restricted to the higher density (approximately 40 pcf) foams and these two types of blowing agents have not been found practical for making low density (less than 10 pcf) extruded polystyrene foams.

EPS foams - Members of the pentane family (neopentane, isopentane, and n-pentane) are most commonly used blowing agents in manufacturing EPS foams. Halocarbons are used to only a very slight extent. Solid chemical blowing agents which release gas upon decomposition as well as carbonate esters that release carbon dioxide have been investigated as alternative blowing agents. The EPS foams compete with extruded polystyrene foam board for insulation and various other applications.

Polyolefin foams - Hydrocarbon blowing agents can be used as substitutes in the manufacture of low density polyolefin foams. It is also possible to make polyolefin foams by the leaching of soluble salts, release of hydrogen by bombardment with high energy electrons, solid chemical blowing agents and injected gases such as nitrogen or CO_2. However these agents do not give low density foams.

e. Opportunities for Recovery of Fluorocarbon Blowing Agents from the Manufacture of Polyurethane Foams

Flexible polyurethane foams - Since the flexible polyurethane foams are formulated to have an open celled structure, the majority (approximately 90 percent) of fluorocarbon blowing agents are lost during the foam manufacturing step. The foams are dispensed from the mixing head onto a belt which moves through an enclosed tunnel. After solidification of the cell structure on the 40-foot conveyor, the foam bun is then sliced and sent to storage.

Of these four steps in the operation--pouring, foam formation on the conveyor, cutting, and warehouse storage--the major source of fluorocarbon loss is from the conveyor. The bun may reach temperatures between 120-160°C due to heat generated by the reaction of the components. This results in volatilization of the fluorocarbon blowing agent. We estimate that 75 percent of the fluorocarbon is lost from this zone. The second most important source of fluorocarbon loss is at the cutting station.

Because of the extreme toxicity of the toluene diisocyanate (TDI) used in the foam formulation, most flexible polyurethane bun lines are extremely well ventilated with hooding over critical areas such as the conveyor and cutting area. Fumes are exhuasted via duct work and a centralized roof fan. Most plants currently discharge the mixture of TDI, CO_2, and fluorocarbon vapors to the atmosphere. Since a sensitivity to even low concentrations of TDI can be developed, the air flows in the vent systems are probably quite high in order to minimize the concentration of TDI in the exhaust. These low concentrations, as well as the potential that TDI has for the poisoning of carbon adsorption systems, represent two problems that could arise in an attempt to recover fluorocarbons from flexible polyurethane foam plants.

Since the liquid mix is relatively cold during the dispensing step, there are no significant losses of fluorocarbon from this stage of the operation.

Rigid foams - Rigid polyurethane foams differ from flexible foams in that they are formulated to have a closed cell structure in order to retain the maximum quantity of blowing agent for the longest possible time. Only minimal quantities (probably less than 5 percent) of the total loss of blowing agent occurs during the manufacturing operation.

The rigid polyurethane foam slab is formed in an enclosed tunnel similar to that used for pouring the flexible foams. The loss of fluorocarbon blowing agent will be primarily from this area and will occur in that portion of the tunnel prior to the solidification of the foam structure. The enclosed tunnel is vented by an arrangement similar to that used for flexible foam manufacture and similarly could be used for the recovery of fluorocarbon blowing agents.

A higher molecular weight polymeric form of TDI is used in fabricating rigid foams. This component is less volatile than TDI itself; hence, the concentrations of TDI in the vent system will be considerably lower than for flexible foam manufacture and the ventilation systems which are used are, therefore, less likely to have the very high flow rates utilized in flexible foam venting systems.

V. CONVERSION TIMETABLES

A. INTRODUCTION

In the event of a restriction in the use or production of a chemical, there is a finite response time before substitutes will be available to satisfy the needs filled by the restricted chemical. The magnitude of economic disruption resulting from restrictions in the use of fluorocarbons or chlorocarbons is critically dependent on the timing of the restrictions and thus the response time available to chemical producers and substitute product producers.

General conversion timetables have been developed so as to define a framework within which to consider timing as a variable in the regulatory options. The following summarizes those steps in a conversion process which could potentially have a significant impact on the time required to replace various chemicals under consideration and the products using them.

Conversion Steps Directly Related to Producing Substitute Chemicals

- Screen alternative chemicals and test utility in intended use.
- Develop process technology for alternative chemicals.
- Develop raw material supplies for producing the new chemical (e.g., new mines, new chemical and physical production facilities).
- Build new plants (or modify existing ones) for the production of the new chemicals.

Conversion Steps Related to Products Using a Substitute Chemical or to a Substitute Product

- Test compatibility of the chemical with other materials and chemicals in intended uses.
- Test products in which the chemical is used for safety and medical acceptability.
- Develop new equipment capable of using the chemical for the intended use (e.g., refrigeration equipment).
- Test new equipment for safety and medical acceptability.
- Expand the production capacity of existing products not using the restricted chemical.

In most cases, definitive predictions of the time required for adequate supplies of a new or substitute product to be available cannot be made. Many of the steps listed above may not be necessary and many can be undertaken in parallel. Any development project involves unpredictable components ranging from unsatisfactory medical test results, to materials and equipment shortages, to lack of consumer acceptance. The probable range of conversion times varies greatly depending on the specific product. Substitute products are currently sold which are intended to satisfy the demand for fluorocarbon aerosol, antiperspirant products. However, there could be serious problems producing sufficient quantities of some components of the substitute products (such as valves for CO_2 aerosols) if a sudden massive conversion were required. In addition, the vast majority of refrigeration equipment uses fluorocarbon products, and an extended period would be required to bring on a new refrigerant and refrigeration system with comparable safety and performance factors.

Since the concern has arisen about the potential effects of fluorocarbon and chlorocarbon emissions on the ozone layer, many of the firms producing the chemicals and producing products using the chemicals have been working to develop substitute chemicals and products. In most cases, the results of this work are not in the public domain and thus cannot be explicitly incorporated in this analysis. The conversion times from this point would be less than if the planning and developments which have been underway had not taken place.

The major chemical producers and consumers (particularly aerosol manufacturers) have regarded restrictions in chemical usage as a serious possibility for the last six months to one year. During this time, efforts have been directed at identifying alternative chemicals and products which do not use potentially restricted chemicals. It is not reasonable to assume that any significant efforts have been directed toward procuring new production facilities for substitute chemicals, their raw materials or products using substitute chemicals. Such efforts would probably not be undertaken until there is a clear regulatory mandate to do so. The discussion here of conversion times implies that a specified number of steps can be undertaken over some period of time and that a "conversion" will be possible. However, one cannot guarantee that new chemicals or products will be found with the desired properties or that they will be commercially successful.

The following discussion of conversion timetables is divided into the major industry sectors identified earlier, moving from raw materials through to the consumer products. These individual sector discussions are followed by a synopsis showing total system conversion timetables and phasing.

B. SECTOR TIMETABLES

1. Raw Materials

If the production of chlorocarbons and fluorocarbons is banned or certain uses banned, two alternative substitution sequences can occur. Either a different chemical can be used in major current uses or different products can be produced which do not use a substitute chemical. For example, a new propellant could be produced for use in aerosols or a non-aerosol product such as a mechanical pump could be used in place of the aerosol.

Under the assumption that a new chemical or new chemicals are produced, the time required for developing adequate raw material supplies can be an important component on the total conversion time. Similar development times can be necessary for producing alternative products, as is discussed later. While the distinction between "Basic Chemicals" and "Raw Materials" is not sharp, these terms are used here to distinguish between the fluorocarbons/chlorocarbons and the chemicals and other products used to produce them. The raw materials may be chemicals produced by the same firms which are producing the fluorocarbons and chlorocarbons.

With the exception of some interchangeability among the halocarbons themselves, viable substitute chemicals have not been publicly identified. It is not possible, therefore, to identify their raw material requirements. As a model, one can consider that all of the chlorocarbons considered by this study consume about 46 percent of total U.S. chlorine production (30 percent excluding vinyl chloride). The fluorocarbons consume about 42 percent of hydrofluoric acid (HF) production. It is possible that a substitute chemical would use these same raw materials. However, if different raw materials are required, the new demand for the materials could require a substantial increase in their production capacity.

Bringing a high-volume source of raw materials on line can be a time-consuming process. Among the elements which may be required are identifying material sources, designing and building processing facilities, and securing adequate energy, transportation, and labor supplies.

Chemical industry sources have estimated that three to five years would be required to develop raw material sources and processing plants. If high volume production of the material is already underway, incremental changes in production capacity would be less. About two years would be required for additional processing facilities at existing plants if necessary. The time required to increase utilization of existing production capacity is negligible relative to the other alternatives. Table V-1 summarizes the time requirements.

The time requirements for raw materials supplies are particularly critical since the major investment required to build the facility will not be made until after there is a firm decision to produce the new chemical. This decision can only come after the chemical product development and testing phases have been substantially completed.

Table V-1. NEW RAW MATERIAL SUPPLY TIMES

Design and construct new plant	3 to 5 years
Add capacity to existing plant	2 years
Usage of existing production capacity	Less than 6 months

Source: Arthur D. Little, Inc., estimates based on chemical industry sources.

2. Basic Chemicals

The times required for bringing production facilities on line for a new substitute chemical are similar to those described above for the raw materials. However, in addition to the time required to design and build (or modify) the production facilities, sufficient time must also be allowed for testing whether the chemical performs as projected, for testing its compatibility with other materials and chemicals, and for testing its safety and toxicity characteristics. Concern for environmental impacts, such as on the ozone layer and on photochemical oxidant levels, can cause additional delays. Since most fluorocarbons and chlorocarbons are consumed in other final products, the viability of these final products using the new chemical must be well established before significant commitments can be made to the chemical production facilities.

If a ban is placed on the production or specified uses of fluorocarbons or chlorocarbons, substitute chemicals may or may not have their process technologies well established. After a screening of alternatives and initial testing phase, the development of the manufacturing technology would typically proceed a period of time before the beginning of the testing for health and safety effects.

During interviews with chemical manufacturers, the approximate elapsed times listed in Table V-2 were developed.

Table V-2. DEVELOPMENT TIMES FOR SUBSTITUTE CHEMICALS

Product Development	
Screen alternative chemicals & test utility in intended use	1 year
Develop new chemical manufacturing technology	2-3 years
Test chemical for environmental, health, and safety effects	1-2 years
Facilities Development Alternatives	
Build new chemical plant	3-5 years
Modify existing chemical plant	2 years
Add capacity to existing chemical plant	2 years
Increase use of existing production capacity	Less than 6 months

Source: Arthur D. Little, Inc., estimates based on chemical industry sources.

3. Chemical Intermediate Applications

As with Raw Materials, the distinction between "Chemical Intermediate Applications" and the Basic Chemicals is not sharp in the usual usage of the terms. Chemical Intermediate Applications are defined in this report to include those uses of the fluorocarbons and chlorocarbons in which they are intermediates or raw materials in a process to produce a final product chemical or plastic. The principal products for which the fluorocarbons and chlorocarbons are intermediates are fluorocarbon resins (i.e., Teflon made from fluorocarbon 22) and tetraethyl lead, tetramethyl lead, silicones, vinylidene chloride, and vinyl chloride made from the chlorocarbons.

The effect of a ban on the production of the fluorocarbons and chlorocarbons would be to end the availability of an important raw material for these high volume chemicals and some smaller volume products. In some cases, alternative manufacturing technologies may be available not using the banned chemical. There is another process for making vinylidene chloride monomer which does not use methyl chloroform. However, such alternatives may not be available in other cases.

As an additional complication, there is no reason to necessarily believe that once a fluorocarbon or chlorocarbon is no longer available, a substitute chemical for use as a propellant or refrigerant will be a satisfactory raw material for the current or reformulated plastic products formerly using the fluorocarbon or chlorocarbon. With methyl chloride, for example, no longer available, the manufacturers of silicones would have to consider alternative products for satisfying the demand for silicone products and alternative process technology/raw materials combinations for making the new product.

The dimensions of these secondary effects of a ban on fluorocarbon and chlorocarbon production have not been explicitly defined. However, the conversion times involved are identical to those described above for the fluorocarbons and chlorocarbons themselves. The economic impact may be greater on the producers of the products using fluorocarbons and chlorocarbons as intermediates than on the fluorocarbon and chlorocarbon producers. As is described in Chapter VI, some producers of tetraethyl lead and the other products are smaller firms for whom these products represent a significant portion of their business. Smaller producers will often have a more difficult time undertaking sudden, major plant changes.

It is difficult to estimate what, if any, effect the involvement of smaller firms would have on industry conversion times as opposed to ending the participation of some firms in the markets. Table V-3 shows the estimated conversion times for the final product producers using the fluorocarbons and chlorocarbons as intermediate chemicals. The times are identical to those for the conversion of the chlorocarbon and fluorocarbon plants to substitute chemicals because the changes involve building new or modifying high volume chemical manufacturing plants.

Table V-3. DEVELOPMENT TIMES FOR PRODUCTION FACILITIES FOR INTERMEDIATE CHEMICAL APPLICATIONS

Product Development Steps	
Screen alternative chemicals and test utility in intended uses	1 year
Develop new chemical manufacturing technology	2-3 years
Test chemical for environmental, health, and safety effects	1-2 years
Facilities Development Alternatives	
Build new chemical plant	3-5 years
Modify existing chemical plant	2 years
Add capacity to existing chemical plant	2 years
Increase use of existing production capacity	Less than 6 months

Source: Arthur D. Little, Inc., estimates based on chemical industry sources.

The economic impact assessment developed in Chapter VII considers restrictions in the use of carbon tetrachloride which is used as an intermediate for making F-11 and F-12 and also considers F-22 used as an intermediate for fluorocarbon polymer. The intermediate applications of other fluorocarbons and chlorocarbons are not considered. As a general rule, the firms using chlorocarbons and fluorocarbons as intermediates would have considerable difficulty responding to a ban in the chemicals, as the conversion times show. However, the results of the economic impact assessment mask this somewhat because, of the chemicals considered, only F-22 is used as an intermediate for products which would not also be banned.

4. Propellant Applications

Approximately 50 percent by weight of U.S. fluorocarbon production is used as a propellant in aerosol products. The majority of propellant usage of fluorocarbons is in hair sprays and antiperspirants/deodorants. If there is a ban on the production of fluorocarbons, the producers of aerosol products are faced with three options: use a non-aerosol product in the present aerosol market; use a compressed gas type propellant; or use a substitute liquified gas propellant if available.

The first option is the most readily available. Products are currently sold which are intended to satisfy the personal product aerosol applications of the fluorocarbons. Due to a combination of factors, but principally consumer preference, the aerosol products have taken over a major market share of the personal products. This is in spite of the aerosol product typically being more expensive on a unit of application basis. While substitute products are currently available, the consumer has perceived a difference between the products and shown a preference in many cases for aerosol products.

The marketers of the aerosol personal products are in the business of supplying the personal products market. Many of the firms now market the non-aerosol alternatives to the products using the fluorocarbons. Thus, the option does exist for the marketers to sell the current substitute products into the aerosol market. These substitutes could include pump sprays, roll-ons, stick applicators, etc. The hair spray market has declined slightly over the past several years because of changing hair styles and the desire for different hair feel.

The time required to increase production of the current substitute products would probably be less than one year. A very large increase would be required in current production. The current production capacity of the glass and plastic bottle manufacturers is substantially larger than the unit production of fluorocarbons/aerosols: glass, 39.5 billion units; and plastic, 7.4 billion units. There were about 1.5 billion fluorocarbon/aerosol units sold in 1973. The procurement and installation of special tooling and processing equipment could be stretched over a period longer than a year if a massive conversion to non-aerosol products is required.

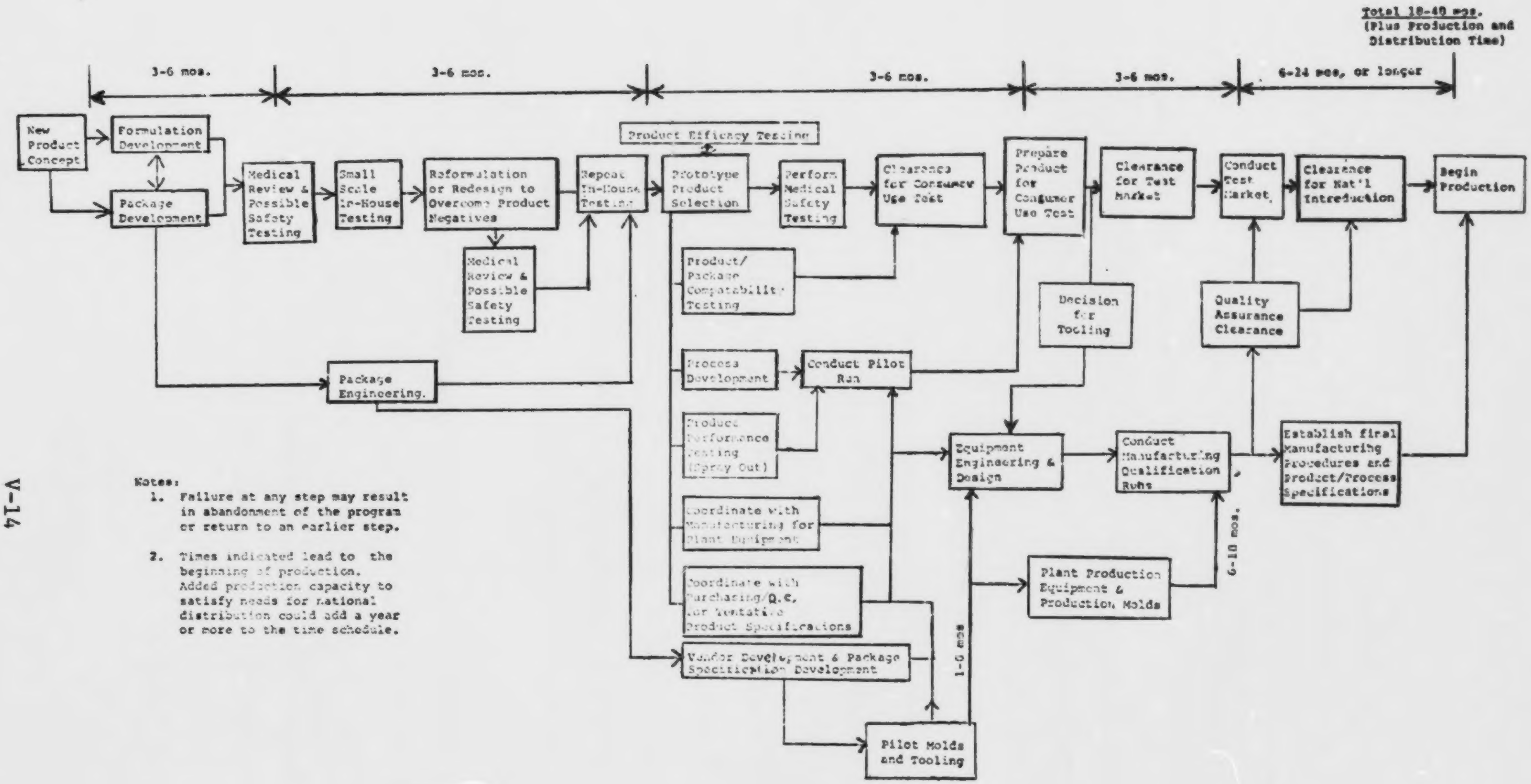
Thus, while it is probably physically possible to be producing large quantities of non-aerosol personal products at the end of one year, it is unlikely that such a massive production shift could or would be undertaken in such a short time frame. In the event the marketers put a complete reliance on the existing non-aerosol products, there would be a large risk associated with placing orders for the product or usage equivalent of 1.5 billion units without knowing the level of total personal product sales in the absence of the aerosols. Under a scenario of total reliance on existing non-aerosol products, the actual transition time to an approximate balance of supply and demand would be in the one to three year range.

The two other options open to the aerosol marketer involve using a new aerosol propellant. Because fluorocarbons are relatively expensive, an interest has existed for a number of years in developing an alternative propellant system. These various alternatives, such as compressed CO_2, have been discussed in Chapter IV. The marketer can begin using one of the compressed gas systems or a substitute liquified gas propellant. The technology for compressed gas aerosols exists, but testing of the acceptance of their different performance characteristics by consumers is only beginning. Hydrocarbon or CO_2 propellants used with methylene chloride as a vapor depressant are now used in at least one aerosol product as a liquified gas propellant system. However, the propellant has not had wide acceptance by aerosol manufacturers. A major development effort may be required to produce a widely accepted liquified gas propellant.

A ban of fluorocarbon production in the near future would force the marketers first to expand the production of their non-aerosol products and in parallel begin developing compressed gas aerosol products. If alternative liquified gas propellants become available, the aerosol products can be reformulated.

Both the compressed and liquified gas aerosol products would be new products requiring a cycle of product designs, testing, manufacturing facility design, equipment procurement, and facilities testing before large-scale production. Figure V-1 was prepared by a major aerosol producer as a generalized flow diagram of a new product introduction schedule. According to the producer's estimates, 18 to 48 months are required to move from new product conception to the beginning of production. This schedule assumes that the various design and testing steps (including health and safety) are generally successful. While some time reductions probably could be achieved during a crash program, the chance for having to repeat steps and stretching the schedule also exists.

As an example of the conversion schedule for introducing the compressed gas products after a fluorocarbon ban, one can use the values in Figure V-1. A similar schedule could not begin for products with a new liquified gas propellant until the chemical was identified and its availability assured. The product introduction schedule would then


Total 18-40 mos.
(Plus Production and Distribution Time)
3-6 mos.
3-6 mos.
3-6 mos.
3-6 mos.
6-24 mos, or longer
New Product Concept
Formulation Development
Package Development
Medical Review & Possible Safety Testing
Small Scale In-House Testing
Reformulation or Redesign to Overcome Product Negatives
Medical Review & Possible Safety Testing
Repeat In-House Testing
Package Engineering.
Product Efficacy Testing
Prototype Product Selection
Perform Medical Safety Testing
Clearance for Consumer Use Test
Prepare Product for Consumer Use Test
Clearance for Test Market
Conduct Test Market
Clearance for Nat'l Introduction
Begin Production
Product/Package Compatability Testing
Process Development
Conduct Pilot Run
Product Performance Testing (Spray Out)
Coordinate with Manufacturing for Plant Equipment
Coordinate with Purchasing/Q.C. for Tentative Product Specifications
Vendor Development & Package Specification Development
Pilot Molds and Tooling
1-6 mos
Decision for Tooling
Equipment Engineering & Design
Conduct Manufacturing Qualification Runs
Plant Production Equipment & Production Molds
6-10 mos.
Quality Assurance Clearance
Establish final Manufacturing Procedures and Product/Process Specifications

Notes:

1. Failure at any step may result in abandonment of the program or return to an earlier step.

2. Times indicated lead to the beginning of production. Added production capacity to satisfy needs for national distribution could add a year or more to the time schedule.

Figure V-1. Flow Diagram of Aerosol Product Introduction Schedule

Source: Industry estimates.

move in parallel with the final stages of bringing the chemical manufacturing plant on line.

Table V-4 summarizes propellant application conversion times The earliest that adequate non-aerosol products would be available after a ban is one year. The introduction of compressed gas products could begin in a year or somewhat later. The introduction of aerosols using liquified gas propellants would be dependent on the further development of alternative chemicals whose time of availability is uncertain.

Table V-4. TIME REQUIRED FOR INTRODUCING PRODUCTS TO PERSONAL CARE MARKET

Expand production of existing non-aerosol products	1-3 years
Introduce compressed gas aerosol products	1-3 years
Introduce liquified gas aerosol products	2-4 years after new propellant identified

Source: Arthur D. Little, Inc., estimates based on aerosol product industry sources.

5. Refrigerant Applications

The refrigeration and air conditioning uses of fluorocarbons present a particularly difficult conversion problem. The refrigerant is a small part of the cost of a refrigerator but there are not significant near-term opportunities for using another refrigerant. Since there appears to be a high potential for recovering a major portion of the fluorocarbons now lost to the atmosphere in refrigeration applications, special consideration has been given to emmission reduction as a regulatory alternative.

The refrigeration industry can be characterized as a high volume manufacturing operation using a technology which has gradually evolved over a number of years. The products must have high reliability with very low health and safety risk. Any product changes come slowly and require a significant capital investment by the manufacturer. Other chemical refrigerants exist and have been used, such as ammonia and sulfur dioxide. However, they have been abandoned for almost all applications because of toxicity or other safety factors. Complicating the regulatory problem if a substitute refrigerant were available are the millions of refrigeration and air conditioning units currently in service which can only operate on the fluorocarbon refrigerant. These units need periodic recharging and would eventually cease functioning if fluorocarbon refrigerants were not available.

Two basic timetables have been considered. The first involves upgrading the existing designs and servicing techniques to reduce refrigerant losses to the atmosphere. The second is an order of magnitude estimate of the conversion time in the event of a total ban of fluorocarbon production.

Table V-5 summarizes the refrigerant uses in the five principal product categories and the current availability of non-fluorocarbon refrigeration systems. One possibility is that fluorocarbon 12 (F-12) will be banned but not fluorocarbon 22 (F-22). The refrigeration and air conditioning equipment now using F-12 cannot use F-22. For most air conditioning applications, products now exist using F-22, but F-22 is not being used for refrigeration applications, nor do successful designs for its use exist. The conversion of refrigeration products to F-22 would require overcoming some major design problems which have been considered by producers in the past but not solved. In product categories now partially using F-22, those producers whose products use F-22 would benefit substantially from an immediate ban on F-12. It is not likely that their production capacity could satisfy the total demand within a year. Within about three years, production of existing products using F-22 could be expanded to meet demand. During this time, the production capacity of F-22 may also have to be expanded.

If F-12 and F-22 are both banned, the refrigeration and air conditioner manufacturers may be forced to switch to absorption systems, whose designs are in some cases now available. Hydrocarbon-based systems using pentane and butane have been used in the past but would not likely be used again because of their explosion danger. Development of a new, safe refrigerant for use in current vapor compression systems would be the option favored by most manufacturers. However, an alternative with properties similar to F-12 and F-22 is not now generally available.

Table V-5. AVAILABILITY OF NON-FLUOROCARBON REFRIGERATION AND AIR CONDITIONING PRODUCTS

Product category	Current refrigerant	Non-fluorocarbon technology now available[a]	Non-fluorocarbon designs now available	Non-fluorocarbon products now available
Appliances	F-12	Yes	Yes	Yes (limited)
Mobile air conditioners	F-12	No	No	No
Room (home) air conditioners	F-22	Yes	No	No
Commercial refrigeration	F-12 and F-502	Yes	No	No
Commercial Air Conditioning (chillers)				
Reciprocating	F-12 & F-22	Yes	Yes	Yes (small)
Centrifugal	F-11, F-12, & F-22	Yes	Yes	Yes

[a] The non-fluorocarbon products for which there are now designs use an absorption technology. Hydrocarbon refrigeration technologies exist but are not viable in most applications for safety reasons.

Source: Arthur D. Little, Inc., based on refrigeration industry sources.

Absorption systems are currently sold for use in the commercial chillers (mostly commercial air conditioning systems). A ban of fluorocarbons would require expanding production of these products. The transition time would be approximately two to three years.

For appliances and home air conditioners, products are not now being sold using the absorption technology. Natural gas companies promoted these applications of the technology for a number of years because they were promoting natural gas as an energy source. While the products were not commercially successful, the specific product designs were developed. They would have to be modified to use different heat sources, for example, but the basic design work has been substantially completed. The time required to modify the designs and procure and set up new manufacturing facilities is estimated to be three to five years.

Designs do not apparently exist for mobile air conditioners, and there appear to be major design problems in adapting the absorption technology to mobile units. While it may be possible to design an absorption system for use in a car, it would be very difficult and there is no assurance of success.

The schedule for bringing products to the market using a new refrigerant could be substantially longer than that required for conversion to absorption systems. In addition to the time required to develop the refrigerant itself, an extensive design, testing, and manufacturing facilities development period would be required. The performance characteristics of the new refrigerant could be substantially different than those of F-12 or F-22 and require a basic redesign of the refrigeration and air conditioning systems. Without knowing the specifications of the refrigerant, the magnitude of this design effort cannot be known. However, in discussions with refrigeration industry sources, an estimate was developed of five to seven years from the time a new design program begins to the beginning of production. The schedule would include a three to five year design and test phase followed by a two year period of further field tests and the procurement of manufacturing equipment.

One regulatory option is the requirement or encouragement of significant reductions in the loss of the fluorocarbon refrigerant to the atmosphere. The loss reduction opportunities occur in both the upgrading of current system designs and improved equipment servicing techniques. Equipment improvements could include substituting flexible metal hoses in mobile air conditioners and the use of self-sealing connectors and precharged components. The servicing improvements could include the recapture of the refrigerant instead of venting it during servicing. The time required for such upgrading and service changes is in the two to three year range.

Table V-6 summarizes the transition times of the refrigeration application alternatives.

Table V-6. TRANSITION TIMES OF REFRIGERANT APPLICATIONS

Product categories	Upgrade current products	Convert from F-12 to F-22	Convert from fluorocarbon to absorption	Convert to new refrigerant[a]
Appliances	2-3 years	3-4 years	4-6 years	3-5 years
Mobile air conditioners	3-4 years	indefinite	indefinite	3-5 years
Room (home) air conditioners	2-3 years	zero time	3-5 years	3-5 years
Commercial refrigeration	2-3 years	3-4 years	4-6 years	3-5 years
Commercial air conditioners (chillers)				
Reciprocating	2-3 years	2-3 years	3-5 years	3-5 years
Centrifugal	2-3 years	1-3 years	2-3 years	3-5 years

[a] Conversion time after new refrigerant is identified and assuming it is available in sufficient quantities.

Source: Arthur D. Little, Inc., estimates based on refrigeration industry sources.

6. Blowing Agent Applications

Fluorocarbons 11 and 12 are used to produce the bubbles in foam plastic products, such as furniture padding and insulation. The plastic material and the fluorocarbon are mixed in a cooled liquid state and then heated. The fluorocarbon vaporizes, producing the bubbles.

Other products have been used as blowing agents prior to the use of fluorocarbons. However, they have generally been flammable, whereas the fluorocarbons are not.

The two strategies for ending or reducing the fluorocarbon emissions from blowing agent applications involve switching to an alternative blowing agent or installing vapor recovery systems. If the fluorocarbons are no longer available, alternative blowing agents or products would be available within one to two years in the major foam markets.

The rigid polyurethane, insulating foams heavily depend on the insulating properties of the fluorocarbons and may not remain competitive with other insulating materials without the fluorocarbon blowing agent. While conversion to another blowing agent may be possible in about two years, requiring some redesign of the products using the foams, there is a likelihood that the product would no longer be competitive with other insulating foams.

In the case of the flexible foams, the fluorocarbons are primarily used as auxiliary blowing agents. In order to approximate the product characteristics now achieved in lower density foams, producers are expected to convert to methylene chloride for a blowing agent if the fluorocarbons are not available and even perhaps if vapor recovery requirements are imposed.

Table V-7 summarizes the blowing agent conversion timetables.

Table V-7. CONVERSION TIMES FOR BLOWING AGENT APPLICATIONS

Develop and install vapor recovery equipment	2-3 years
Substitute blowing agent in rigid foam applications	3 years
Substitute blowing agent in flexible foam applications	6 months

Source: Arthur D. Little, Inc., estimates based on industry sources.

In the manufacture of flexible polyurethane foams, the various vapors emitted in the production process are collected and vented to the atmosphere because they are toxic. To recapture the fluorocarbon portion of the vapors, one would want to use a carbon adsorption system. However, isocyanate, which is also in the vapor stream, will poison the system. While in principle it may be possible to get around this problem, adequate fluorocarbon recovery equipment for use with the flexible foams does not now exist. A two to three year development and installation period may be required. For these reasons, the producers seem likely to convert to methylene chloride as a blowing agent rather than install the vapor recovery equipment.

The vapors from the manufacture of rigid polystyrene foams are not collected. If collection systems are installed, the recapture of fluorocarbon emissions during production by carbon adsorption may be less technically difficult than in the case of the flexible foams because of the absence of poisoning agents in the vapor. One should, however, regard a two to three year development and installation period as also being representative of the response time for rigid foam manufacturers to requirements for reducing fluorocarbon emissions.

7. Solvent Applications

Fluorocarbons and chlorocarbons are used in a wide variety of solvent applications. These uses include high quality cleaning of electronic components, dry cleaning, and general degreasing in metal working. While there are selected industries which primarily perform a cleaning function, these activities do not adequately characterize the solvent applications of fluorocarbons and chlorocarbons. The availability of solvents is critical to a variety of sectors such as printed circuit manufacturers, textile manufacturers, and the Defense Department.

The advantages and disadvantages of using various solvents were discussed in detail earlier. Since there is a significant opportunity for reducing losses to the atmosphere, this vapor recovery option has been added to conversion options.

While the products have considerable performance differences, there is substantial cross-over usage among the solvents and the different applications. The major solvent used in dry cleaning in the U.S. for example is perchloroethylene. Limited quantities of DuPont's "Valclene" (F-113) are also used. European dry cleaners also use trichloroethylene and F-11. The impact on solvent applications will depend on which chemicals are controlled. The regulatory alternatives discussed in Chapter VII include methyl chloroform but not the other principal solvents used in the U.S.

If some of the fluorocarbon and chlorocarbon solvents are banned, the first option for the users would be alternative fluorocarbon or chlorocarbon solvents. If all of the fluorocarbon and chlorocarbon production is ended, substitutes such as water-based or hydrocarbon-based solvents would be used. This is not to say that their performance is equivalent to the chlorocarbon/fluorocarbon solvents. In general, the substitute solvents and the technology for using them are available. The conversion time for movement to the substitutes is in the one to two year range for many applications.

By suggesting the potential for substitute solvents, one must allow for the possibility of very specialized uses of the chlorocarbons or fluorocarbons which are not readily satisfied by alternative solvents. Techniques or technologies such as associated with micro-circuitry may have developed based on the availability of the solvents. The implications of an end to the availability of the solvents in all their applications have not been determined.

Of the five chemicals considered in the economic impact assessment of Chapter VII, only methyl chloroform has major solvent uses. Many users of methyl chloroform as a solvent could switch to F-113, though it also may ultimately be included in fluorocarbon use restrictions. Trichloroethylene has only limited potential as an alternative because of its impacts on photochemical oxidant levels in urban areas. Some special applications, such as printed circuit boards, may be dependent on the properties of methyl chloroform and could not easily substitute another solvent. In general, solvent users will be able to move to substitutes for methyl chloroform such as F-113, perchloroethylene, water or hydrocarbon-based solvent, but not without difficulty and some sacrifice in performance/cost.

For the high-value solvents such as fluorocarbon 113, substantial efforts are made to recover vapor emissions. The technology for vapor recovery in most applications is now widely available. It is technically possible to make improvements in vapor recovery by the end of one year following the issuance of the necessary regulations or price incentives. However, there may be important constraints on the availability of certain components of the vapor recovery equipment such as carbon adsorption units which could stretch out the conversion by one or more years.

Table V-8 summarizes the conversion times for the regulatory alternatives.

Table V-8. CONVERSION TIMES FOR SOLVENT APPLICATIONS

Convert to different fluorocarbon/chlorocarbon solvent	1-2 years
Convert to new solvent (when available)	1-2 years (after becoming available)
Upgrade vapor recovery practices	1-2 years

Source: Arthur D. Little, Inc., based on chemical industry contacts.

C. PHASING OF CONVERSION TIMES

For each of the industry sectors now consuming the potentially restricted fluorocarbons and chlorocarbons, two conversion timetables are of primary interest. The first is the time required to bring to the market a sufficient quantity of a substitute product to meet the demand now satisfied by the product using the fluorocarbon or chlorocarbon. As an example, the time required to manufacture and distribute roll-on and stick antiperspirant products would be the first conversion time if a ban were placed on the use of fluorocarbons in aerosol antiperspirants. The second conversion time of primary interest is that required to bring on line a substitute chemical with similar characteristics to the fluorocarbons and chlorocarbons and then reformulate the existing products to use the new chemicals. For the antiperspirant, a new liquified gas propellant may have to be developed, followed by the reformulation and testing of the aerosol antiperspirant product.

These two conversion times represent, first, the response or conversion times of the consuming sectors to an abrupt, near-term ban on their use of the chemicals. The second response time is that required to develop a substitute chemical with properties similar to the banned chemical and to reformulate the consuming products. Because the second response time is substantially longer than the first, the second represents potential (but not certain) long-term conversion strategy. If there is a ban of the chemicals in the next one or two years, the consuming sectors would have to pursue the first set of conversion strategies and then wait to see if new chemicals became available in the future and decide then whether a reconversion was possible or necessary.

Table V-9 summarizes the primary response times of the chemical consuming industries to an immediate (six months, for example) ban on the production or use of the fluorocarbons and chlorocarbons. In most instances, the response would be to introduce into the existing markets products which now exist but have not been able to compete with products using the fluorocarbons or chlorocarbons.

The fastest response time for the propellant applications is one to two years, during which the production capacity of substitute products would be expanded and market acceptance would be tested. Major segments of the refrigeration industry could not market substitute products until about three years after a ban in the fluorocarbons. This time would be spent adopting absorption technology to the various refrigeration products and gearing up the necessary manufacturing facilities. The intermediate chemicals are a major exception to the general rule of available substitute products. While some substitute products may be available, a ban of some of the chlorocarbons and fluorocarbons could require substantial chemical process technology development, new final product development and testing, and new facilities development. A two to seven year range must be assumed as a possible "fastest" conversion time.

When considering the time required to bring on line substitute chemicals as opposed to substitute products, there are a number of important uncertainties which cannot be resolved at this point. It is not publicly known whether viable substitute chemicals have been identified or what their potential uses or characteristics would be. If a substitute is identified, one cannot now say whether it is a product already being produced or whose production technology is well known. The substitute

Table V-9. CONSUMING INDUSTRY RESPONSE TIME TO AN IMMEDIATE CHEMICAL BAN

Consuming industry	Response time [a]	
Intermediate chemical applications	2-7 years	
Propellant applications	1-2 years	
Refrigerant applications[b]	to absorption	to F-22
Appliances	4-6 years	3-4 years
Mobile air conditioners	indefinite	indefinite
Home air conditioners	3-5 years	zero
Commercial refrigeration	4-6 years	3-4 years
Commercial air conditioners		
- reciprocating	3-5 years	2-3 years
- centrifugal	2-3 years	1-3 years
Blowing agent applications		
Rigid foams	3 years	
Flexible foams	six months	
Solvent applications	1-2 years	
(Convert to non-regulated fluorocarbons or chlorocarbons)		

[a] The primary response times of the consuming industries to a ban of fluorocarbon and chlorocarbon usage are the elapsed times required for the industries to introduce substitute products to meet the demand now satisfied by controlled chemicals or products using the chemicals.

[b] In the event of a ban of F-11 and F-12, most refrigerant applications would be converted to F-22. If F-22 were also banned, the products would be converted to absorption systems or to other suitable refrigerants.

Source: Arthur D. Little, Inc., based on industry sources.

chemical might require major efforts to develop a manufacturing technology and then to build new production plants.

Figures V-2 and V-3 were constructed to illustrate an "Optimistic" and a "Pessimistic" sequencing of the steps required to bring a substitute chemical into production. Under the "Optimistic" scenario, the following assumptions were made:

1. The screening and testing of substitute chemicals has been underway for one year before the ban is imposed.
2. The chemical manufacturing technology for producing the substitute chemical is already well established.
3. The necessary raw materials are already being produced and their production capacity simply needs to be expanded.
4. The manufacturing facilities for the new chemical would be conversions or expansions of existing facilities.

Under this set of optimistic assumptions, about three and a half years is required to begin production of the substitute chemical after the fluorocarbon or chlorocarbon is banned.

The "Pessimistic" scenario assumes each of the required steps for bringing on a new chemical must be carried out in its entirety. The specific assumptions made were the following:

1. A substitute chemical had not been identified or tested at the time the ban was imposed.
2. A reliable process technology for the chemical must be developed.
3. Adequate raw material supplies do not exist and new raw material plants must be built.
4. New chemical production plants must be built.

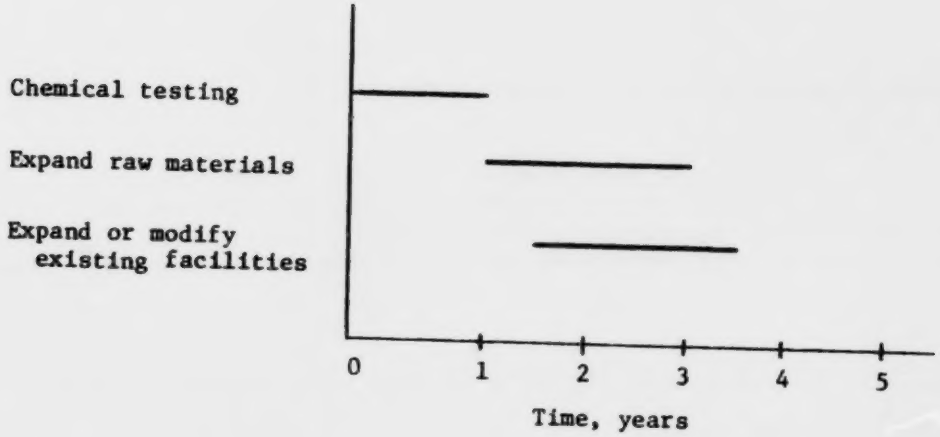


Figure V-2. "Optimistic" Time Sequence for Producing Substitute Chemical[a]

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[a] Assumes:
1) screening and testing of substitute chemical has been underway one year before ban.
2) chemical process technology for producing substitute exists.
3) raw materials are secured by an expansion of existing sources.
4) the new chemical processing facilities would be expansions or conversions of existing facilities.

Source: Arthur D. Little, Inc., estimates based on chemical industry sources.

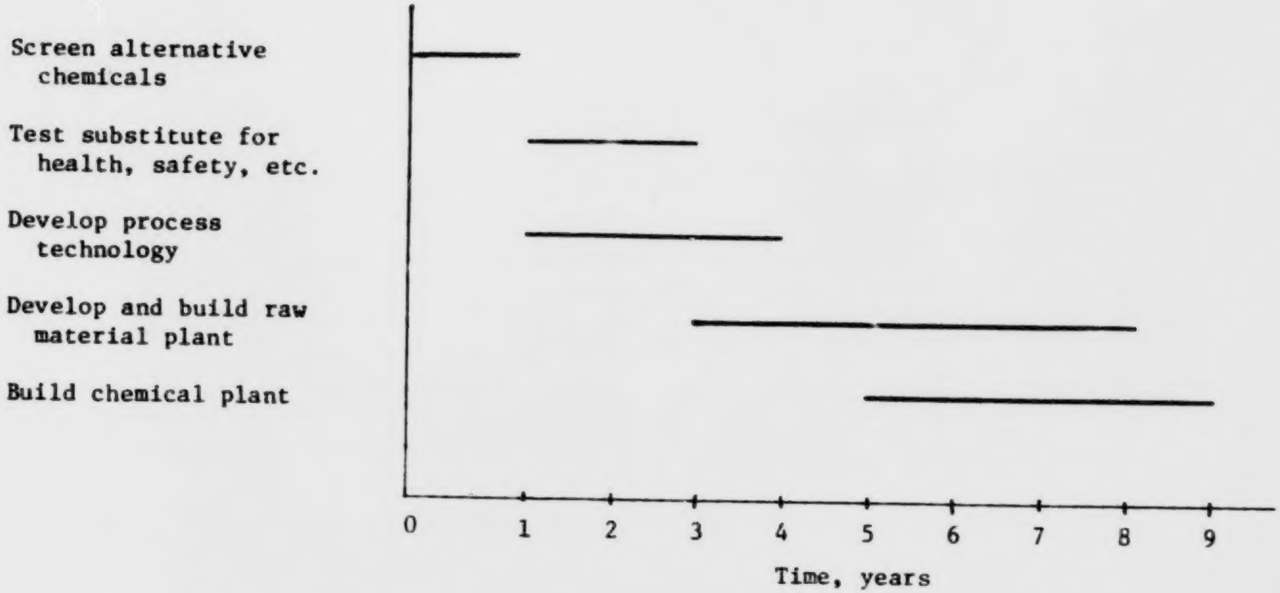

Figure V-3. "Pessimistic" Time Sequence for Producing Substitute Chemical[a]

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[a] Assumes: 1) substitute chemical has not been identified at time of ban.
2) reliable process technology for producing the chemical does not exist.
3) adequate raw material supplies do not exist.
4) new chemical production plants must be built.

Source: Arthur D. Little, Inc., estimates based on chemical industry sources.

Under this set of pessimistic assumptions, nine years would be required to begin production of a substitute chemical after the imposition of a ban on fluorocarbon/chlorocarbon production.

Without knowing specifically what the substitute chemical will be, the possible range of times necessary to simply begin producing a substitute chemical must be bracketed at between 4 to 9 years. The conversion of one producer from trichloroethylene to methyl chloroform for major solvent applications is an analogous situation. In 1966, trichloroethylene was identified as a contributor to smog in Los Angeles. In 1973, seven years later, the production facilities for methyl chloroform came on line. The same producer had identified a new pesticide in 1966, but the production plant was not operational until 1975.

When considering potential chemical conversion times, one can regard a three to four year conversion time as being a minimum, and a seven to nine year conversion time as a likely maximum.

If the substitute chemical is to be used as a final product, such as in solvent applications, the production of the chemical itself is the beginning of the product availability in its final form. When the chemical is to be used as an input to other final products, time required for the reformulation or redesign of the consuming products is an important component of the total time required to bring new consuming products to the market. Forty-nine percent of the 1973 U.S. production of fluorocarbons was used as an aerosol propellant. From the standpoint of the producer of a chemical substitute to the fluorocarbon, it is critically important to know whether the substitute can and will be used in the propellant applications. This information must be known before the producer commits himself to production capacity for which there is no market. The decisions by potential users of the chemicals, such as refrigeration manufacturers and aerosol manufacturers, may be the determining factors as far as whether and when substitute chemicals would be produced.

Figure V-4 illustrates how the conversion times of the chemical manufacturer and the aerosol producer sequence under optimistic and pessimistic chemical conversion assumptions. The elapsed time from the announcement of the ban to the beginning of production of the chemical and the aerosol products would be between four and ten years. These times are longer than simply beginning production of the chemical because major investments in chemical production facilities and developing production technologies will be delayed until the viability of aerosol products using the new propellant can be established. The four to ten year range of conversion times would be applicable to F-11 and F-12, which are predominantly used as propellants.

Figure V-5 illustrates the sequence of conversion times for moving to a new chemical refrigerant. Again using the optimistic and pessimistic alternatives, the conversion time range is from four and a half to ten and a half years. The times are slightly longer than for the aerosol applications because more time may be required to verify the utility of the chemical in the new refrigeration system than would be necessary in aerosol products. The conversion range of four and a half to ten and a half years would be representative of the time required to convert from refrigeration systems using fluorocarbon refrigerants to non-fluorocarbon liquid refrigerants.

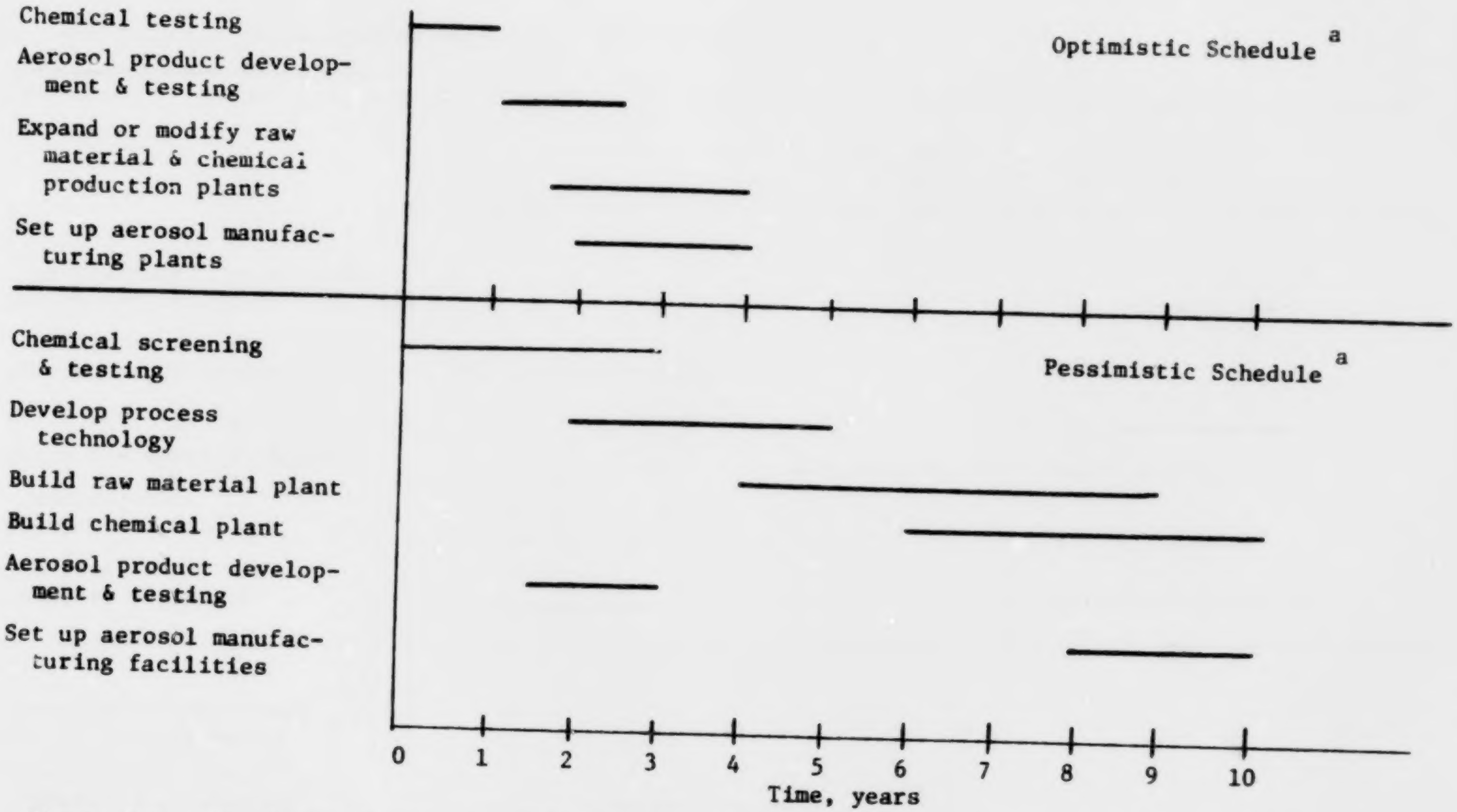

Figure V-4. "Optimistic" and "Pessimistic" Time Schedules for Converting to a New Liquified Gas Propellant

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[a] See text for definition of optimistic and pessimistic schedules.

Source: Arthur D. Little, Inc., estimates based on industry sources.

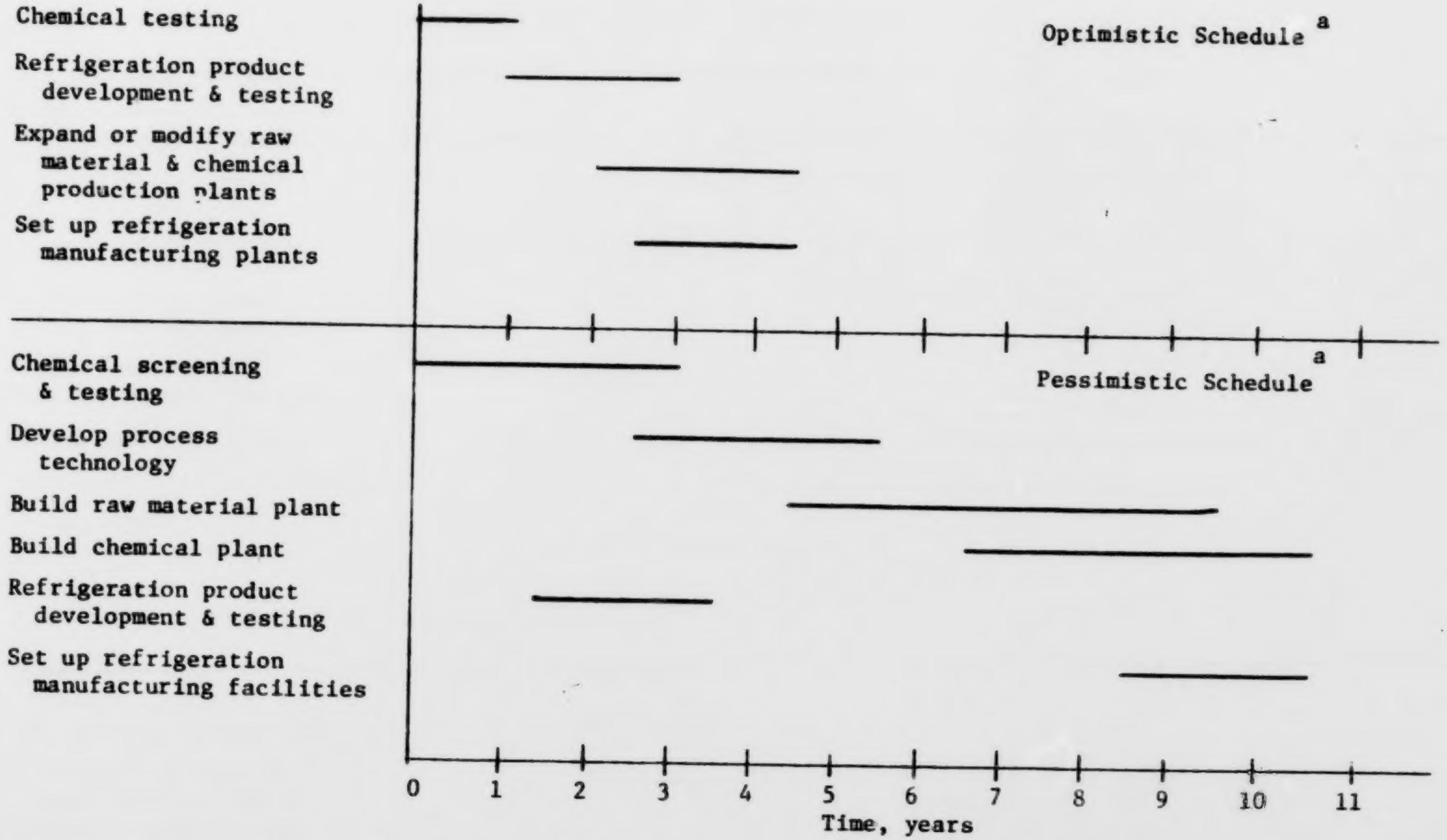

Figure V-5. "Optimistic" and "Pessimistic" Time Schedules for Converting to New Chemical Refrigerant.

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[a] See text for definition of optimistic and pessimistic schedules.

Source: Arthur D. Little, Inc., estimates based on industry sources.

Table V-10 summarizes the estimated times required to convert to a new chemical in the major fluorocarbon and chlorocarbon use sectors. These values are in contrast with those in Table V-9 which show what now appear to be the earliest the major consuming industries will be able to introduce products taking the place of those currently using the fluorocarbons and chlorocarbons. In the event of a ban, the industry sectors would undertake the conversion strategies represented by Table V-9. In parallel, they could wait for substitute chemicals to be developed and then consider the reformulation or redesign of their products with the new chemicals. Table V-10 lists the estimated times for this second set of conversion strategies.

In addition to the opportunities for conversion to substitute products or substitute chemicals, the opportunities for reducing emissions to the atmosphere which were discussed earlier are summarized in Table V-11. The estimated times required to upgrade equipment or modify processing facilities are listed on the table. These response times are short relative to other options and in some cases can significantly reduce losses to the atmosphere.

As is discussed in Chapter III, there are small atmospheric losses due to manufacturing and transporting the chemicals. However, the losses during their intended uses are far greater, and it is the reduction of these use losses that are summarized in Table V-11.

Table V-10. CONSUMING INDUSTRY CONVERSION TIMES TO USING SUBSTITUTE CHEMICALS

Consuming industry	Conversion times[a]
Intermediate chemical applications	5 to 10 years
Propellant applications	4 to 10 years
Refrigerant applications	5 to 11 years
Blowing agent applications	
- flexible foams	six months
- rigid foams	4 to 9 years
Solvent applications	4 to 9 years

[a] The conversion times to substitute chemicals are those required to develop new chemicals with properties similar to the banned compounds and to modify the products using the banned chemicals.

Source: Arthur D. Little, Inc., estimates based on industry sources.

Table V-11. TIMES REQUIRED FOR EQUIPMENT UPGRADING TO REDUCE ATMOSPHERIC LOSSES

Industry sector	Response times
Refrigerant applications	2 to 4 years
Blowing agent applications	2 to 3 years
Solvent applications	1 year

Source: Arthur D. Little, Inc., estimates based on industry sources.

VI. DEFINITION OF PRIMARY AFFECTED INDUSTRY SECTORS

A. INTRODUCTION

The purpose of this chapter is to define the major industry sectors which potentially may be significantly impacted by restrictions on the chlorocarbons and fluorocarbons under investigation in this report. Since the various sectors are so highly interrelated, we have shown the flow of products from raw materials, such as chlorine, through various hydrocarbon and chlorocarbon intermediates to final products, among which are the fluorocarbons in question.

Each of these interrelated sectors could be impacted by a fluorocarbon ban or limitation. The level of impact, however, would be a function of the timing and extent of specific regulatory actions. This chapter, therefore, examines the industry participants and their respective dependence on fluorocarbons and chlorocarbons as a base for discussing the impact of alternative regulatory scenarios and resulting potential economic impacts in Chapter VII.

We have concentrated on defining industry sectors directly involved with manufacture and use of fluorocarbon materials. Impacts for indirectly related industries, such as the transportation or the retail areas , have not been studied and should be considered in a subsequent analysis.

B. INDUSTRY STRUCTURE

1. Sector Relationships

The overall structure of the industry associated with fluorocarbon manufacture is complex and highly interrelated. Figure VI-1 illustrates the progression from relatively simple and basic raw materials such as chlorine and raw hydrocarbons through several intermediates, and finally to fluorocarbon and related products and their respective major end uses. This figure is meant only to show generalized product relationships and may differ somewhat from a producer's specific manufacturing practice. The various components and the interrelationship of the fluorocarbon-related industries are best described by examining each product class separately.

a. Basic Raw Materials

The fundamental raw materials for fluorocarbon production are hydrocarbons, hydrofluoric acid and chlorine. Chlorine is a basic industrial chemical--produced from the electrolysis of brine--with applications in a wide range of organic and inorganic products, as shown in Table VI-1. In terms of consumption, by far the most important end uses for chlorine are in the manufacture of chlorocarbons, which accounted for over 45 percent of 1973 domestic chlorine demand. A more detailed description of chlorocarbon manufacture and end use is found in the next section of this report.

Other major feedstocks for fluorocarbon manufacture are light hydrocarbons — methane, ethane, propane, n-butane — obtained primarily from natural gas or from petroleum refinery operations. Natural gas supplies, however, are becoming scarcer and petrochemical manufacturers

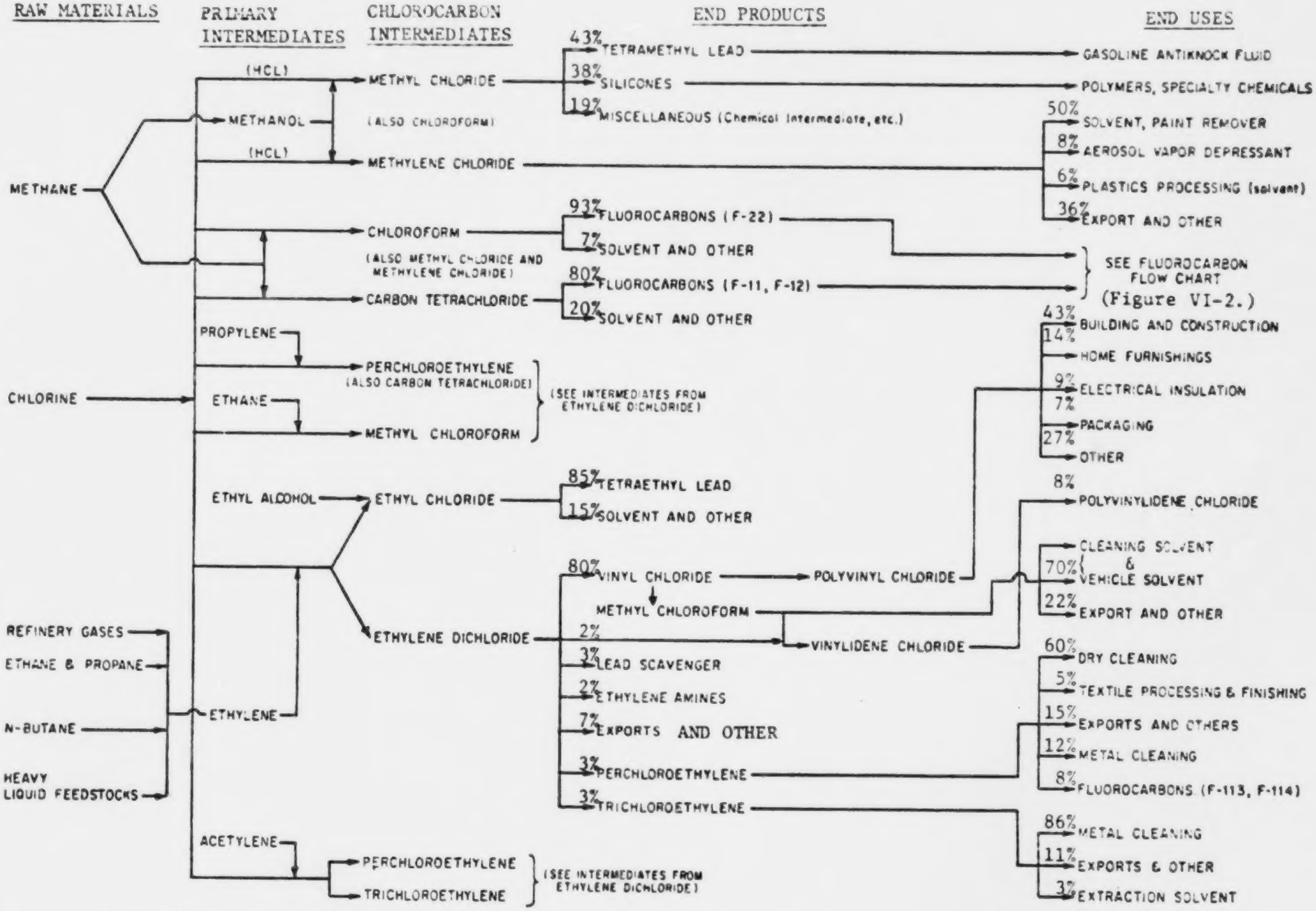
RAW MATERIALS
PRIMARY INTERMEDIATES
CHLOROCARBON INTERMEDIATES
END PRODUCTS
END USES
METHANE
CHLORINE
REFINERY GASES
ETHANE & PROPANE
N-BUTANE
HEAVY LIQUID FEEDSTOCKS
(HCL)
METHANOL
(HCL)
PROPYLENE
ETHANE
ETHYL ALCOHOL
ETHYLENE
ACETYLENE
METHYL CHLORIDE
(ALSO CHLOROFORM)
METHYLENE CHLORIDE
CHLOROFORM
(ALSO METHYL CHLORIDE AND METHYLENE CHLORIDE)
CARBON TETRACHLORIDE
PERCHLOROETHYLENE
(ALSO CARBON TETRACHLORIDE)
METHYL CHLOROFORM
(SEE INTERMEDIATES FROM ETHYLENE DICHLORIDE)
ETHYL CHLORIDE
ETHYLENE DICHLORIDE
PERCHLOROETHYLENE
TRICHLOROETHYLENE
(SEE INTERMEDIATES FROM ETHYLENE DICHLORIDE)
43% TETRAMETHYL LEAD
38% SILICONES
19% MISCELLANEOUS (Chemical Intermediate, etc.)
93% FLUOROCARBONS (F-22)
7% SOLVENT AND OTHER
80% FLUOROCARBONS (F-11, F-12)
20% SOLVENT AND OTHER
85% TETRAETHYL LEAD
15% SOLVENT AND OTHER
80% VINYL CHLORIDE
METHYL CHLOROFORM
2%
3% LEAD SCAVENGER
2% ETHYLENE AMINES
7% EXPORTS AND OTHER
3% PERCHLOROETHYLENE
3% TRICHLOROETHYLENE
POLYVINYL CHLORIDE
VINYLIDENE CHLORIDE
GASOLINE ANTIKNOCK FLUID
POLYMERS, SPECIALTY CHEMICALS
50% SOLVENT, PAINT REMOVER
8% AEROSOL VAPOR DEPRESSANT
6% PLASTICS PROCESSING (solvent)
36% EXPORT AND OTHER
SEE FLUOROCARBON FLOW CHART (Figure VI-2.)
43% BUILDING AND CONSTRUCTION
14% HOME FURNISHINGS
9% ELECTRICAL INSULATION
7% PACKAGING
27% OTHER
8% POLYVINYLIDENE CHLORIDE
CLEANING SOLVENT & VEHICLE SOLVENT
70%
22% EXPORT AND OTHER
60% DRY CLEANING
5% TEXTILE PROCESSING & FINISHING
15% EXPORTS AND OTHERS
12% METAL CLEANING
8% FLUOROCARBONS (F-113, F-114)
86% METAL CLEANING
11% EXPORTS & OTHER
3% EXTRACTION SOLVENT

Figure VI-1. Materials Flow Chart - Chlorocarbons - 1973

Source: Arthur D. Little, Inc., estimates.

Table VI-1. U.S. CHLORINE PRODUCTION AND MAJOR END USES - 1973
(thousands of tons)

Organic compounds	Demand	Percent of total
One-carbon (C_1)	1,550	15
Two-carbon (C_2)	3,000	29
Three-carbon (C_3)	620	6
Cyclic	517	5
Oxygen containing	1,035	10
Total organic	6,722	65
Non-organic		
Inorganic chemicals	1,240	12
Pulp and paper	1,345	13
Water treatment	520	5
Total non-organic	3,105	30
Unspecified	533	5
Total	10,360	100

Source: U.S. International Trade Commission and Arthur D. Little, Inc., estimates.

are looking increasingly toward heavy liquid feedstocks such as naphtha and gas oil as the source of light hydrocarbons. Technologies for heavy liquid cracking and reforming are being developed currently and over the next 5-10 years should play an increasingly important role as sources for hydrocarbons suitable for conversion to chlorocarbons and fluorocarbons.

b. Primary Intermediates

The hydrocarbon raw materials described in the previous section are processed to yield an extremely important group of industrial intermediates--ethylene, propylene, acetylene, methanol, ethanol, and others. Ethylene is the largest volume olefin produced in the United States, with 1973 production in excess of 22 billion pounds, and is produced either via ethane reforming or heavy liquid cracking. Virtually all ethylene produced is used as a precursor for derived products--polyethylene, ethylene glycol, and ethylene dichloride, which in turn are either processed further or, in the case of polyethylene, consumed directly.

Another important primary intermediate related to fluorocarbon production is propylene, which is produced either via propane reforming or heavy liquid cracking, much like ethylene. Propylene finds use as a precursor for polypropylene, an increasingly important plastic, as well as for propylene glycol and the chlorocarbon, perchloroethylene. Propylene production in 1973 was nearly 10 billion pounds, placing it second in overall olefin production. Another noteworthy intermediate is acetylene, which has experienced declining production recently, as alternate intermediates (most directly ethylene and propylene) have proven more economical in the manufacture of downstream products.

Acetylene, however, is produced from a variety of hydrocarbon feedstocks and is used in the manufacture of a limited amount of perchloroethylene and trichloroethylene. Ethanol and methanol are also used as precursors for chlorocarbons such as methyl chloride, methylene chloride, and ethyl chloride, as well as directly as solvents and in other uses. Table VI-2 summarizes the 1973 production and major end uses for each of these primary intermediates.

Although chlorine, itself, is used directly in the production of most chlorocarbons, a small amount of hydrogen chloride (HCl) is used to produce methyl chloride and methylene chloride. In addition, substantial amounts of HCl, which is produced as a byproduct of chlorocarbon manufacture, are recycled and oxidized to produce makeup chlorine via oxychlorination or the relativetly new Kel-Chlor process. Approximately 5 to 10 percent of the total amount of chlorine required for chlorocarbon manufacture is supplied from HCl recycle.

c. Chlorocarbon Intermediates

As indicated in Figure VI-1 the chlorocarbons represent a second class of intermediate which result from the processing via chlorination or hydrochlorination of primary intermediates such as ethylene or propylene. In turn, these chlorocarbon intermediates are generally processed further into fluorocarbons and other chlorinated materials such as polyvinyl chloride. However, some chlorocarbons, such as perchloroethylene, trichloroethylene, and methyl chloroform have direct application as solvents, degreasing agents, cleaning agents, and in other uses which use about 25 percent of the total production of the 10 chlorocarbons studied.

Table VI-2. U.S. PRODUCTION AND END USES OF HALOCARBON PRIMARY INTERMEDIATES - 1973

Chemical	Production	Major end uses	Percent
Ethylene	22,329 million lb	Polyethylene	40
		Ethylene dichloride	13
		Ethylene glycol	12
		Ethylbenzene	8
		Ethyl alcohol	6
		Other	21
Propylene	9,880 million lb	Acrylonitrile	21
		Polypropylene	29
		Other[a]	50
Acetylene	380 million lb	Acrylates	26
		Vinyl chloride monomer	23
		Acetylenic chemicals	20
		Vinyl acetate	17
		Chlorinated solvents	4
		Other	10
Methanol	960 million gal	Formaldehyde	45
		General process solvents	10
		DMT	7
		Methyl halides	4
		Methyl amines	4
		Exports	5
		Miscellaneous	21
Ethanol	285 million gal	Chemical intermediates	26
		Toiletries & cosmetics	20
		Acetaldehyde	9
		Industrial solvent & thinner	12
		Detergents, flavors & disinfectants	10
		Miscellaneous	23

[a] Includes allyl chloride, butyraldehydes, cumene, dodecene, heptene, isopropyl alcohol, nonene, propylene oxide.

Sources: *Chemical Marketing Reporter*, U.S. International Trade Commission, and Arthur D. Little, Inc., estimates.

The C_1 chlorocarbons include methyl chloride, methylene chloride, chloroform, and carbon tetrachloride. The majority (60 percent) of methyl chloride is produced via hydrochlorination of the primary intermediate, methanol, with the remainder being produced via direct chlorination of methane. Methylene chloride on the other hand is predominantly produced via direct chlorination of methane, which produces methyl- and methylene chloride as coproducts. Carbon tetrachloride and chloroform are also produced via direct chlorination as coproducts. In addition, about 25 percent of carbon tetrachloride production capacity is based on carbon disulfide and a small amount of carbon tetrachloride is obtained as a by-product of perchloroethylene manufacture.

The C_2 chlorocarbons include perchloroethylene, trichloroethylene, ethyl chloride, and ethylene dichloride (EDC), and, together with C_1 chlorocarbons, constitute the chlorocarbon intermediates for the fluorocarbons examined in this study. With over 9 billion pounds produced in 1973, ethylene dichloride is the largest-volume chlorocarbon intermediate. Derivatives include vinyl chloride, perchloroethylene, and trichloroethylene. Table VI-3 details the end-use pattern for EDC in 1973 and shows that its dominant use was as the precursor for vinyl chloride manufacture. EDC in addition served as the precursor for 85 percent of the estimated 450 million pounds of the trichloroethylene, and 50 percent of the 700 million pounds of perchloroethylene produced, respectively, in 1973. Chlorination of acetylene accounts for the remaining 15 percent of trichloroethylene, and 5 percent of perchloroethylene production. The remaining 45 percent of perchloroethylene production is via propylene chlorination.

d. End Products and Uses

The end products for which chlorocarbon intermediates serve as precursors are extremely large in number and widespread in use. In

Table VI-3 U.S. ETHYLENE DICHLORIDE END USE - 1973
(millions of pounds)

Total EDC reported production	9,293 million lb.	
End use	Amount	Percent of reported production
Vinyl chloride	8,197	87.9
Trichloroethylene	339	3.6
Perchloroethylene	212	2.3
Ethylene amines	132	1.4
Vinylidene chloride	109	1.2
Miscellaneous	10	0.1
Lead scavenger	250	2.7
Exports	368	4.0
Total	9,617[a]	103.2

[a] Includes estimate of EDC production not reported

Source: U.S. International Trade Commission and Arthur D. Little, Inc. estimates.

addition to fluorocarbons, C_1 chlorocarbon derivatives include tetramethyl lead, silicones, solvents, and others which find end uses in polymers, paints, aerosols, gasoline anti-knock agents, and numerous other end uses. Table VI-4 summarizes C_1 chlorocarbon derivative end-use applications and their respective amounts of chlorocarbon intermediates consumed in 1973.

C_2 chlorocarbon derivatives likewise find widespread and important end uses. Most notable is polyvinyl chloride, a versatile cost-effective plastic, which accounted for over 4.5 billion pounds or nearly 86 percent of vinyl chloride production in 1973. PVC production alone accounted for nearly 15 percent of total U.S. chlorine demand in 1973. Other important C_2 chlorocarbon derivatives include tetraethyl lead, ethylene amines, polyvinylidene chloride and others which find end uses in textiles, gasoline anti-knock compounds, solvents, and in export markets. In addition, substantial amounts of two C_2 chlorocarbons, perchloroethylene and trichloroethylene, are used directly as dry cleaning and metal degreasing agents. Table VI-5 summarizes 1973 C_2 chlorocarbon derivative end uses and volumes.

2. Chlorocarbon and Fluorocarbon Product and Material Flows

a. Chlorocarbon Intermediates

Figure VI-2 summarizes in greater detail the product and material flows of the fluorocarbons under consideration and their intermediate chlorocarbon precursors, carbon tetrachloride, chloroform, and perchloroethylene. As pointed out in the previous section, these three materials are only several of the many C_1 and C_2 chlorocarbon intermediates which are highly interrelated by virtue of either common primary intermediate precursors or similar derivative end products. Chloroform and carbon

Table VI-4. U.S. PRODUCTION/RAW MATERIALS FOR C_1 CHLORINATED HYDROCARBONS - 1973 (millions of pounds)

Chlorocarbon production	Chlorocarbon consumption
Methyl chloride (544/247)[a]	Tetramethyl lead (235/130)[b] Silicone (205/110) Miscellaneous - chemical intermediates and solvents (104/57)
Methylene chloride (520/820)	Paint remover, solvent (260/410) Aerosols (40/65) Rubber processing (30/45) Exports and other (190/300)
Chloroform (253/454)	Fluorocarbon 22 (205/368) Solvents and other chemical intermediates (48/86)
Carbon tetrachloride (1047/1610)	F-11 (415/640) F-12 (632/970) Other (small)

[a] (methyl chloride production/chlorine consumption)

[b] (methyl chloride use/chlorine equivalent)

Source: U.S. International Trade Commission and Arthur D. Little, Inc. estimates.

Table VI-5. U.S. PRODUCTION/RAW MATERIALS FOR C_2 CHLORINATED HYDROCARBONS - 1973
(millions of pounds)

Chlorocarbon production	Chlorocarbon consumption
Ethylene dichloride (9617/3890)[a]	Vinyl chloride (8197/3315)[b]
	Trichloroethylene (339/135)
	Perchloroethylene (212/85)
	Ethylene amines (132/50)
	Vinylidene chloride (109/45)
	Lead scavenger (250/100)
	Exports and miscellaneous (378/160)
Methyl chloroform (548/724)	Metal cleaning and degreasing (384/507)
	Vinylidene chloride (44/58)
	Exports and other (120/159)
Perchloroethylene (706/1062)	Dry cleaning solvent (424/637)
	Textile processing (35/53)
	Fluorocarbons (58/88)
	Metal cleaning (83/127)
	Exports and other (106/157)
Trichloroethylene (452/624)	Metal cleaning (389/537)
	Exports (50/69)
	Solvents and chemical intermediates (13/18)
Ethyl chloride (660/100)	Tetraethyl lead (560/85)
	Solvents and chemical intermediates (100/15)

[a] (ethylene dichloride production/chlorine consumption)

[b] (vinyl chloride use/chlorine equivalent)

Source: U.S. International Trade Commission and Arthur D. Little, Inc. estimates.

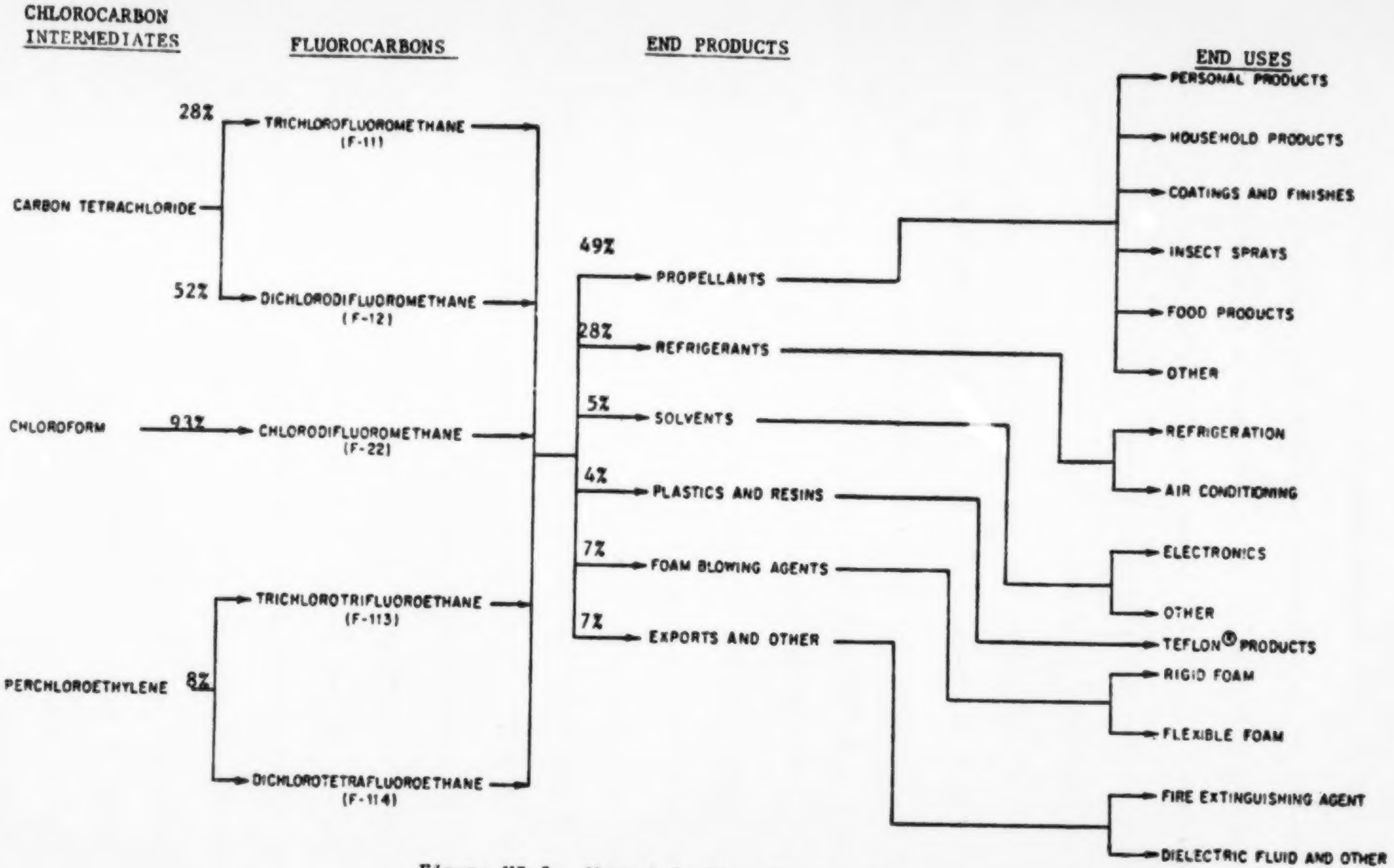
CHLOROCARBON INTERMEDIATES
FLUOROCARBONS
END PRODUCTS
END USES
CARBON TETRACHLORIDE
28%
52%
TRICHLOROFLUOROMETHANE (F-11)
DICHLORODIFLUOROMETHANE (F-12)
CHLOROFORM
93%
CHLORODIFLUOROMETHANE (F-22)
PERCHLOROETHYLENE
8%
TRICHLOROTRIFLUOROETHANE (F-113)
DICHLOROTETRAFLUOROETHANE (F-114)
49%
PROPELLANTS
28%
REFRIGERANTS
5%
SOLVENTS
4%
PLASTICS AND RESINS
7%
FOAM BLOWING AGENTS
7%
EXPORTS AND OTHER
PERSONAL PRODUCTS
HOUSEHOLD PRODUCTS
COATINGS AND FINISHES
INSECT SPRAYS
FOOD PRODUCTS
OTHER
REFRIGERATION
AIR CONDITIONING
ELECTRONICS
OTHER
TEFLON® PRODUCTS
RIGID FOAM
FLEXIBLE FOAM
FIRE EXTINGUISHING AGENT
DIELECTRIC FLUID AND OTHER

Figure VI-2. Materials Flow Chart - Fluorocarbons - 1973

Source: Arthur D. Little, Inc., estimates.

tetrachloride are principally produced via thermal chlorination of methane, while perchloroethylene is primarily produced from ethylene dichloride which, as pointed out previously, has other important derivatives such as polyvinyl chloride. Table VI-6 summarizes 1973 production and end-use data for these three chlorocarbon intermediates.

b. Fluorocarbon End Products

Table VI-7 summarizes the raw materials requirements for the three fluorocarbons F-11, F-12, and F-22 in 1973 and the indirectly related raw material requirements for major fluorocarbon end uses. The major fluorocarbons F-11 and F-12 are manufactured from carbon tetrachloride, and they accounted for 40 and 60 percent respectively of carbon tetrachloride domestic use in 1973. Since industry sources indicate that 10-20 percent of production of carbon tetrachloride is for other uses including exports, it is believed that reported production is understated. It is estimated that approximately 415 million pounds of carbon tetrachloride was utilized in 1973 in the production of F-11. The related raw material requirements are 55 million pounds of hydrofluoric acid and indirectly 370 million pounds of chlorine required for the production of carbon tetrachloride utilized in the production of F-11. In the related end-use markets, an estimated 615 million pounds of carbon tetrachloride or 59 percent of 1973 production was required for the production of F-11 and F-12 for use as aerosol propellants.

Fluorocarbon 22 represents a major portion of the total demand for chloroform or 81 percent of chloroform production in 1973. A similar analysis is provided in Table VI-7 on the related requirements for chloroform in its related end-use markets.

In addition to the importance of the demand for basic chemicals such as chloroform and carbon tetrachloride in fluorocarbon production, the

Table VI-6. U.S. PRODUCTION/RAW MATERIALS FOR CARBON TETRACHLORIDE, CHLOROFORM, PERCHLOROETHYLENE - 1973

(millions of pounds)

Chlorocarbon production		Chlorocarbon consumption	
Carbon tetrachloride	1047	F11	415
		F12	632
		Other	Small
Chloroform	253	F22	205
		Solvents, other	48
Perchloroethylene	706	Fluorocarbons	58
		Dry cleaning solvent	424
		Textile processing	35
		Metal cleaning	83
		Exports and others	106

Source: U.S. International Trade Commission and Arthur D. Little, Inc., estimates.

Table VI-7. U.S. FLUOROCARBON CONSUMPTION OF RAW MATERIALS - 1973
(millions of pounds)

	End-Use	Percent	Chlorine demand	Percent of total domestic chlorine demand
Chloroform production total	253		454	2.2
Fluorocarbon 22		81	320	(1.8)
Plastics (PTFE)	50			
Refrigerants	150			
Propellant and other	5			
Export	11	4		
Other	37	15		
		100		
Carbon tetrachloride Production total	1047		1610	7.7
Fluorocarbon 11	415	39.7	640	(3.1)
Blowing agent	65			
Propellant	295			
Refrigerant	25			
Export and other	30			
Fluorocarbon 12	632	60.3	970	(4.6)
Refrigerants	205			
Propellants	320			
Blowing agent	22			
Export and other	85			
Other	Small			
		100		

Source: U.S. International Trade Commission, and Arthur D. Little, Inc. estimates.

related chlorine and hydrofluoric acid demand is significant. As indicated previously, 9.5 percent of domestic chlorine demand is related to fluorocarbon production. Also, based on the estimated end-use patterns for the fluorocarbons, it is estimated that fluorocarbon propellant applications account for 4.6 percent of total domestic chlorine demand. Approximately 305 million pounds of hydrofluoric acid were utilized in the production of F-11, F-12, and F-13 in 1973. This represents greater than 40 percent of the total U.S. production of hydrofluoric acid in 1973.

The estimated end-use patterns and levels of consumption of the principal fluorocarbons are summarized in Table VI-8.

3. Related Business Activities

A summary of the related business activities for fluorocarbons is summarized in Table VI-9. The basic chemical producers of fluorocarbons as well as raw material producers of chlorocarbons, i.e., chlorine and hydrocarbon intermediate manufacturers, and hydrofluoric acid would be significantly impacted if fluorocarbon use were restricted. In addition there are a number of related industries which consume fluorocarbons which would be impacted including aerosol manufacturers, refrigeration equipment manufacturers, plastics processing, resin producers and fluorocarbon solvent consuming industries. Aerosol manufacturing is done by both custom fillers, which provide the filling capability for aerosol marketers, and by filler/marketers which have integrated backward from their marketing operations.

Table VI-8. PRODUCTION/RAW MATERIAL FOR FLUOROCARBONS - 1973

Raw materials	Fluorocarbons	End uses
(million pounds)	(million pounds)	(million pounds)
Carbon tetrachloride (415) HF (55)	Fluorocarbon 11 (334)	(53) Foam blowing agent (18) Refrigerant (23) Export and others (240) Propellant
Carbon tetrachloride (632) HF (180)	Fluorocarbon 12 (489)	(168) Refrigerants (10) Foam (61) Export and other (250) Propellant
Chloroform (205) HF (70)	Fluorocarbon 22 (136)	(35) Resins (11) Propellant and other (90) Refrigerants

Fluorocarbons

Percent of total chlorine demand	-	9.5
Percent of total chlorine demand for propellants	-	4.6
Percent of total HF production		41.6
Percent of total carbon tetrachloride production	-	96.5
Percent of total chloroform production	-	81.0

Source: U.S. International Trade Commission, and Arthur D. Little, Inc. estimates.

Table VI-9. RELATED BUSINESS ACTIVITIES - FLUOROCARBONS

CHEMICAL MANUFACTURE		SUPPLY SECTORS		END-USE INDUSTRIES		
Raw Materials • chlorocarbons producer • hydrofluoric acid producer		**Equipment and Materials** • can manufacturers • cap & valve manufacturers • filling equipment manufacturers • ingredient suppliers • other	→	**Aerosol Manufacturing** • custom filler • filler/marketer	→	• aerosol marketer
↓						
Basic Chemicals • fluorocarbons producers → (to all end-use industries)		**Equipment and Materials** • condensor, compressor, heat exchange manufacturer • other	→	**Refrigeration** • refrigeration equipment manufacturers • household freezer/refrigerator manufacturer	→	• contractors • service • sales
• polyether and polyester polyols	→	→	→	**Plastics Processing** • foam manufacturers • foam product manufacturer		
				Resins and Solvents		

Source: Arthur D. Little, Inc.

Also, there are a number of related suppliers of equipment and materials which may be impacted if fluorocarbon propellant use in aerosols is restricted. The principally affected sectors would be can manufacturers, cap and valve manufacturers, ingredient suppliers, and filling equipment manufacturers. There are obviously a number of other supplier sectors from packaging to transportation, however, in the context of the proportion of a total industry sector impacted, these sectors would experience a much smaller impact.

The refrigeration industry is an important sector which utilizes fluorocarbons. Potential impact sectors are refrigeration equipment manufacturers and household freezer and refrigerator manufacturers. Related industries are the equipment and materials suppliers including manufacturers of condensors, compressors, heat exchangers and other refrigeration equipment parts. In addition, in the end-use sectors there are refrigeration equipment contractors and service and sales related personnel.

Other fluorocarbon related industries include plastics processing, resin producers, and solvent users. The principal industry sectors in plastics processing which may be impacted include the foam manufacturers and the foam product manufacturers which utilize foam in the manufacture of products such as pillows, cushions, and furniture, and raw material suppliers of polyether and polyester polyols. Resin manufacture includes such products as Du Pont's Teflon which is used in a variety of consumer products. Fluorocarbon solvents are principally used in the aerospace and electronics industries.

C. PRIMARY INDUSTRY SECTOR DEFINITION

This section further defines the primary industry sectors which would be affected by restrictions on the production or use of fluorocarbons and chlorocarbons. Identification efforts have been focused on those industries which would be directly affected through a loss of employment, production, and/or sales in relation to the levels which may have occured without regulation. Therefore, sectors which may be indirectly affected, such as transportation or carton manufacture, have been excluded, while industry sectors such as chemical raw material producers, aerosol fillers, and refrigeration equipment manufacturers have been included.

In defining the primary sectors, the levels of sales, production and employment have been presented where this information is available. The levels of industry activity directly related to the chemicals under investigation and their fraction of total sector activity have been defined (i.e., the proportion of hydrofluoric acid production used in the manufacture of fluorocarbons). Finally, the major companies involved in each industry sector have been identified and the estimated importance of business activities relating to the chemicals under investigation -- relative to overall company activity -- has been determined when relevant data were available. Although individual company effects are identified in this section and although these effects are small for most companies, it should be noted that the total economic impact, in terms of inflation and employment effects at the national level,will be at least as large as dictated by the sum of these individual parts.

1. Raw Materials - Major raw materials for the key compounds of interest are discussed below.

a. Chlorine - Chlorine is an important raw material for the production of the fluorocarbons and chlorocarbons under consideration. Table VI-10 summarizes chlorine demand in pertinent end-use markets. As indicated, depending upon the restrictions placed on fluorocarbons and chlorocarbons, the potential impact on the chlorine industry can vary significantly. Also, the potential impact on individual companies will vary extensively based on the dependence of a company's chlorine production on production of certain chlorocarbons and/or fluorocarbons -- either through captive utilization or sales in the merchant market. Other uses of chlorine include use as a raw material for the production of other organic chemicals and inorganic chemicals, use in the pulp and paper industry, water treatment, and miscellaneous applications. There is a high level of captive use of chlorine production, with an estimated 47 percent of production in 1973 being consumed captively by related industries.

The major U.S. producers of chlorine are listed in Table VI-11. The table shows each producer's production capacity and their relative share of total U.S. chlorine capacity. Because of a high proportion of captive utilization, it is difficult to measure individual company sales of chlorine. For purposes of this report, a manufacturer's value of production has been determined based on each company's percent of total industry capacity and an average production, or "plant gate" sales value for chlorine based on merchant sales in 1973. The value of chlorine production as a percent of total company chemical sales is used as a

Table VI-10. SELECTED CHLORINE DEMAND CATEGORIES - 1973

End-use category	Percent of total demand	Comments
Chlorocarbons[a] (total)	45.6	Indicates total chlorocarbon demand level
Chlorocarbons (excluding vinyl chloride)	29.6	Demand level net of the single largest component
Methyl chloroform, carbon tetrachloride & chloroform[b]	13.0	Demand level directly related to 5 key chemicals
Chloroform for F-22 and carbon tetrachloride only	9.5	Demand level directly related to F-11,F-12,& F-22
Carbon tetrachloride (indirect chlorine demand for fluorocarbons F-11 & F-12)	7.7	Demand level directly related to F-11 & F-12

a. Includes methyl chloride, methylene chloride, chloroform, carbon tetrachloride, perchloroethylene, trichloroethylene, methyl chloroform, and vinyl chloride.

b. Includes chlorine demand for chloroform utilized in production of F-22 and carbon tetrachloride used in production of F-11 and F-12.

Source: Arthur D. Little, Inc. estimates.

Table VI-11. U.S. CHLORINE PRODUCERS - 1973

Company	Capacity [a] (million lb/yr.)	Percent of total capacity	Value of Production [b] ($million)	Total company chemical sales ($million)	Value of production as a percent of total company chemical sales
Dow Chemical	7,920	31.9%	157.9	2,250	7.0
PPG Industries	2,400	9.7	47.8	440	10.8
Diamond Shamrock	2,304	9.3	45.9	454	10.1
Occidental Petroleum	1,930	7.8	38.5	1,080	3.6
Allied Chemical	1,188	4.8	23.7	1,114	2.2
Olin	1,170	4.7	23.3	370	2.3
BASF Wyandotte	1,116	4.5	22.2	356	6.2
Stauffer Chemical	706	2.8	14.1	621	2.3
Pennwalt	684	2.7	13.6	246	5.5
FMC	568	2.3	11.3	745	1.5
Ethyl Corporation	460	1.9	9.2	499	1.8
Kaiser	386	1.6	7.7	N/A	
Shell Oil	270	1.1	5.4	748	0.7
Vulcan Materials	270	1.1	5.4	62	8.7
DuPont	244	1.0	4.9	4,250	0.1
B. F. Goodrich	216	0.8	4.3	452	1.0
Monsanto	180	0.7	3.6	2,355	0.2
Paper companies	496	2.0	9.9		
Other	1,888	7.6	37.8		
Total	24,396	100.0%	486.5		
Production (1973)	20,804				

[a] Capacity as of January 1, 1975

[b] Based on average value of commercial shipments of $46.77/ton in 1973

Sources: Chemical Marketing Reporter, U.S. Dept. of Commerce, Current Industrial Reports Series M28A; and company annual reports.

measure of the importance of chlorine production to the company's total chemical sales. Although the total chlorine requirement for the production of fluorocarbons F-11, F-12 and F-22, carbon tetrachloride and methyl chloroform represents approximately 13 percent of total domestic chlorine demand, the value of chlorine production related to these compounds is less than one to two percent of total company chemical sales for most of the chlorine producers. There are instances where a company's chlorine production is more dependent on these chemicals than the typical level of several percent. In particular, Vulcan Materials utilizes a high portion (ca. 15 percent) of its chlorine production for the production of chloroform, carbon tetrachloride, and methyl chloroform. Therefore, Vulcan's chlorine production level may be more severely affected than others' if limitations are placed on these chemicals or the fluorocarbons derived from them. The details of Vulcan's position (and those of other manufacturers) are discussed later in this chapter.

The chlorine industry is dominated by Dow Chemical which has 32 percent of total U.S. capacity. The second largest producer, PPG Industries, has only 10 percent of U.S. capacity. The industry is relatively concentrated, with the top seven producers having over 70 percent of total capacity. Capacity utilization for chlorine production was relatively high in 1974 and chlorine was generally in tight supply. However, the economic downturn in late 1974 and early 1975, coupled with recent capacity additions, has reduced industry capacity utilization and has made the supply of chlorine more plentiful.

Because of the uncertainties surrounding a number of environmental or health considerations relating to chemicals derived from chlorine (i.e., vinyl chloride and fluorocarbons) and the lead time in constructing new chlorine production capacity, it is possible that there will be limited capacity expansions over the next several years. If the economy turns around as expected in late 1975 and early 1976, chlorine could again be in tight supply by 1977/78. This could mitigate the impact of reduced demand resulting from restrictions on the production or use of certain fluorocarbons or chlorocarbons.

Estimated employment in the production of chlorine is 10,300 employees based on reported employment in "Chlorine and Alkalis," Census of Manufactures, 1972. Related employment for chlorine used in the production of methyl chloroform, carbon tetrachloride, and chloroform (for fluorocarbons only) is an estimated 1,350 employees -- pro-rated based on 13.0 percent of total chlorine demand utilized in the production of these three chlorocarbons.

b. Hydrofluoric Acid - Hydrofluoric acid (HF) is a major raw material in the production of fluorocarbons. The use of hydrofluoric acid in fluorocarbons represents a major portion of the total end-use of hydrofluoric acid: about 42 percent of the total domestic hydrofluoric acid demand in 1973. The other major uses of hydrofluoric acid are in the production of aluminum, in petroleum refining, the production of fluoride salts, stainless steel pickling, uranium processing, and miscellaneous applications. Total production of hydrofluoric acid was 731 million pounds in 1973. A large portion of hydrofluoric acid is used captively (50.8 percent in 1973). The total value of production in 1973 was $135.6 million, assuming that production is valued at the average price for merchant manufacturer's sales of $18.55 per 100 pounds. The value of production related to fluorocarbon production was $56.3 million in 1973 (42 percent of total value).

Table VI-12 presents the major U.S. producers of hydrofluoric acid and their production capacities. In addition, the table shows estimated value of HF production (based on each producer's proportional share of total production) and the value of production as a percent of each company's total chemical sales in 1973. One fact stands out: the value of production of hydrofluoric acid for Essex Chemical was 19.5 percent of total chemical sales, a substantial portion of the total company chemical sales in 1973. A large portion of Essex's hydrofluoric acid production is utilized in the production of fluorocarbons via a partially owned subsidiary, Racon.

Production of hydrofluoric acid in the U.S. is highly concentrated. Allied Chemical and DuPont share over 50 percent of U.S. production capacity. As indicated above, a large portion of hydrofluoric acid production is utilized in the manufacture of fluorocarbons. Furthermore, some companies are more dependent on the production of fluorocarbons than others. Essex Chemical is an example of one of these companies. On the other hand, producers of hydrofluoric acid such as Alcoa and Kaiser would be less severely affected because their production of hydrofluoric acid is predominantly used in the production of aluminum.

Total estimated employment in the production of hydrofluoric acid is 800. Employment related to the production of fluorocarbons (F-11, F-12, F-22) is estimated to be 330 based on the percent of total HF production used in the production of fluorocarbons (41.6 percent). A

Table VI-12. U.S. HYDROFLUORIC ACID PRODUCERS - 1973

Producer	Capacity (million lb/yr.)	Value of production[a] ($million)	Total company chemical sales ($million)	Value of production as a percent of total company chemical sales
Allied Chemical	216	36.8	1,114	3.3%
DuPont	200	34.1	4,250	0.8
Alcoa	110	18.7	N/A	
Kaiser	100	17.0	N/A	
Pennwalt	50	8.5	246	3.4
Harshaw Chemical (Division of Kewanee Oil)	36	6.1	140	4.4
Stauffer Chemical	36	6.1	621	1.0
Olin	26	4.4	370	1.2
Essex Chemical	32	3.7	19	19.5
Total	796			
Production	731.0[1]	135.4		

[1] 91.8% capacity utilization

Fluorocarbon	Production (million lb)	HF Consumption (million lb)	Percent of total HF
F-11	333.8	55	7.5%
F-12	489	180	24.6
F-22	136.5	70	9.5
		305	41.6%

[a] Based on $18.55/100 lb in 1973

Sources: Chemical Marketing Reporter, U.S. International Trade Commission, U.S. Dept. of Commerce, Current Industrial Reports Series M28A; company annual reports; and Arthur D. Little, Inc., estimates.

summary of estimated employment in the production of hydrofluoric acid is presented in Table VI-13.

The hydrofluoric acid producers operated under a high level of capacity utilization in 1973: 91.8 percent of total domestic capacity. In 1974 capacity utilization dropped to approximately 80 percent of total capacity because of reduced demand for fluorocarbons and aluminum. Historic growth over the 1963-1973 time period for hydrofluoric acid was approximately 7.5 percent per year. Future growth of hydrofluoric acid is expected to be lower than historical levels. One reason is that in the aluminum industry hydrofluoric acid is being replaced by fluosilicic acid. Also, the recycling of fluorides in waste water treatment programs is reducing demand for hydrofluoric acid. Finally, increased imports from Mexico and Canada are expected to replace future domestic production growth of hydrofluoric acid.

Table VI-13. EMPLOYMENT IN HYDROFLUORIC ACID PRODUCTION

	Million Pounds of production per employee	HF production (million lb)	Employment
Production Workers	1.3	731	560
Sales, technical and Other overhead Staff	3.0	731	240
Total employment in HF production			800
Total HF Related to Fluorocarbon Production		305	330

Sources: U.S. Dept. of Commerce, Current Industrial Reports Series M28A; and Arthur D. Little, Inc., estimates based on discussions with industry.

2. Basic Chemicals

a. Fluorocarbons - There are six companies in the United States presently manufacturing fluorocarbons, of which three companies account for 85 percent of total domestic capacity. DuPont, Allied Chemical, and Union Carbide are the principal producers with 41.8 percent, 25.9 percent and 16.7 percent respectively of domestic capacity in 1973.

The total manufacturer's value of fluorocarbons was $242.1 million in 1973 as shown in Table VI-14. This value of fluorocarbon production is an estimate, since each producer manufacturers a different proportion of the various fluorocarbons. It is assumed that the average value of fluorocarbons production at the manufacturer's level was 25.2¢ per pound in 1973. The historical growth rate of fluorocarbon production from 1962-1972 has been 8 percent annually. Future growth had been estimated at 5 percent per year, assuming unrestricted use.

Table VI-15 summarizes the chemicals sales of the major producers of fluorocarbons and their related value of production of fluorocarbons. Fluorocarbon production value ranges from 30.8 percent of total chemical sales for Racon in 1973 to 9.5 percent and 5.6 percent of total chemical sales in 1973 for Pennwalt and Allied Chemical. For the remaining companies the value of production of fluorocarbons represents less than 3 percent of total company chemical sales.

Estimated employment in the production of fluorocarbons is 2200-2700 employees. This estimate is based on industry contacts and on an estimate determined through related employment figures in the Census of Manufactures, 1972. The production of fluorocarbons represents 2.7 percent of the total

Table VI-14. U.S. FLUOROCARBON MANUFACTURERS - 1973

	Allied Chemical	DuPont	Kaiser	Pennwalt	Racon	Union Carbide	TOTAL
Capacity (million lb/yr)	310	500	50	115	20	200	1,195
Percent of U.S. capacity	25.9%	41.8%	4.2%	9.6%	1.7%	16.7%	100%
Production[a] (million lb/yr)	248	401	40	92	16	160	957
Manufacturer's value ($million)	$62.7	$101.5	$10.1	$23.3	$4.0	$40.5	$242.1[b]

[a] includes F-11, F-12, F-22

[b] manufacturer's value based on 1975 price is estimated at $450-500 million

Sources: Chemical Marketing Reporter, U.S. International Trade Commission, and Arthur D. Little, Inc., estimates.

Table VI-15. DEPENDENCE OF MANUFACTURERS ON FLUOROCARBON SALES

Company	Total chemical sales (1973, $ million)	Value of fluorocarbon production ($ million)	Percent of total chemical sales
Allied Chemical	$1,114	$62.7	5.6%
DuPont	4,250	101.5	2.4
Kaiser	375	10.1	2.7
Pennwalt	246	23.3	9.5
Racon [a]	13	4.0	30.8
Union Carbide	2,400	40.5	1.7

[a] Racon's sales are 100% dependent on fluorocarbons; manufacturer's value of production understates actual retail sales level.

Sources: Corporate annual reports, and Arthur D. Little, Inc., estimates.

value of shipments of Industrial Organic Chemicals, N.E.C. Based on this proportion, employment in fluorocarbon production is an estimated 2700 employees, including production workers and related employment.

b. Chlorocarbons - An analysis of the chlorocarbon industry in the United States shows that nearly the entire volume of the nine[a] chlorocarbons discussed below were produced by fourteen companies in 1973. Of these fourteen companies, eight manufacture five or more of the chlorocarbons. However, for individual chemicals, the industry is often dominated by a few large chemical companies. Over 70 percent of these chlorocarbons are used as a chemical intermediate in the production of other chemicals, although if ethylene dichloride use for the production of vinyl chloride is excluded, approximately 30 percent of these chlorocarbons are used as chemical intermediates. Therefore, there is often a high level of captive use of the chlorocarbons and the value of production is included in the final product produced. Since it is difficult to determine a company's captive use vs. merchant sales (this information is generally proprietary), the manufacturer's value of production has been determined for each company's production of chlorocarbons as a measure of their importance in relation to each producer's total chemical sales.

Table VI-16 summarizes estimated production and manufacturer's value of carbon tetrachloride for the principal producers. These estimates are prorated based on each producer's share of production capacity and an estimated average production value for carbon tetrachloride in 1973. The estimated

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[a] Carbon tetrachloride, chloroform, ethyl chloride, ethylene dichloride, methyl chloride, methyl chloroform, methylene chloride, perchloroethylene, and trichloroethylene. Vinyl chloride is treated separately at the end of this section.

Table VI-16. U.S. CARBON TETRACHLORIDE MANUFACTURERS - 1973

	Allied Chemical	Dow	DuPont	FMC	Stauffer	Vulcan Materials	Total
Capacity[a] (million lb/yr)	8	275	500	300	420	75	1578
Percent of total U.S. capacity	0.5	17.4	31.7	19.0	26.6	4.8	100
Production[b] (million lb/yr)	5	182	332	199	279	50	1047
Production value[c] ($ million)	0.3	10.9	19.9	11.9	16.7	3.0	62.7

[a] 1975 capacity estimates.

[b] Based on proportional share of total domestic capacity.

[c] Based on average price of merchant sales in 1973.

Sources: Directory of Chemical Producers, U.S. International Trade Commission, and Arthur D. Little, Inc., estimates.

total manufacturer's value of carbon tetrachloride produced in the United States was $62.7 million in 1973. The estimate for DuPont is overstated because, DuPont's carbon tetrachloride production capacity was operating well below reported capacity estimates in 1973.

U.S. production of carbon tetrachloride has grown at an average annual rate of 7.3 percent from 1963-1973 and 6.8 percent from 1968-1973 with even lower growth in recent years. Future growth has been anticipated to continue at about 5 percent per year through 1977, however, carbon tetrachloride growth is dependent on fluorocarbon growth which is currently unpredictable.

The principal United States producers of chloroform and their related production capacities are summarized in Table VI-17. There are six domestic producers while two producers, Dow and Stauffer, have 42.2 percent and 24.4 percent respectively or 66.6 percent of total domestic capacity. The estimated production value of chloroform was $17.7 million for 1973 and the producers operated at an estimated 82 percent of production capacity. Since the production capacities are flexible, the capacity utilization estimate is based on reported capacities and does not reflect the producers ability to shift production to other coproducts in the thermochlorination process.

U.S. production of chloroform increased at an average annual rate of 9.2 percent between 1963 and 1973. Growth over the last five years has been only 6.8 percent per year and at an even lower rate recently. Ultimately the demand for chloroform depends on the demand for fluorocarbon refrigerants

Table VI-17. U.S. CHLOROFORM MANUFACTURERS - 1973

	Allied Chemical	Diamond Shamrock	Dow	DuPont	Stauffer	Vulcan Materials	Total
Capacity (million pounds per year)	30	18	130	15	75	40	308
Percent of total U.S. capacity	9.7	5.8	42.2	4.9	24.4	13.0	100
Production (million pounds per year)	25	15	107	12	62	33	254
Production value ($ million)	1.7	1.0	7.5	0.9	4.3	2.3	17.7

Sources: Directory of Chemical Producers, U.S. International Trade Commision, and Arthur D. Little, Inc., estimates.

and for fluorocarbon plastics. Demand is expected to grow at an average rate of 5 percent per year over the next five years with the largest proportional increase from the increased production of fluorocarbon polymers. This forecast assumes no limitations are placed on fluorocarbons for use in refrigeration or plastics.

Ethyl chloride is produced by six companies in the United States with Ethyl Corporation,the major producer,having over 40 percent of total production capacity. The major producers and related capacities are summarized in Table VI-18. The estimated production value of ethyl chloride in 1973 was $46.3 million and producers were operating at 77 percent of capacity. Since ethyl chloride is principally used as a chemical intermediate in the production of tetraethyl lead, there is a high level of captive consumption (59 percent in 1973).

Growth in production of ethyl chloride has been static over the past five years because of environmental pressures against tetraethyl lead. Future growth is uncertain, and is dependent on environmental restrictions on leaded gasoline as well as reduced growth in demand for gasoline as a result of energy conservation efforts.

Ethylene dichloride is the most important chlorocarbon in terms of production volume and market value. The reported sales value is low because of the large amount of captive use of the product(which was 85 percent in 1973) but estimated production value was $279.3 million (see Table VI-19).

Table VI-18. U.S. ETHYL CHLORIDE MANUFACTURERS - 1973

	American Chemical[a]	Dow	DuPont	Ethyl Corp.	PPG	Shell	Total
Capacity (million pounds per year)	110	75	110	360	120	85	860
Percent of total U.S. capacity	12.8	8.7	12.8	41.9	14.0	9.9	100
Production (million pounds per year)	85	57	85	277	92	65	661
Production value ($ million)	5.9	4.0	5.9	19.4	6.5	4.6	46.3

[a] American Chemical has been consolidated into Stauffer Chemical Corporation

Sources: Directory of Chemical Producers, U.S. International Trade Commission, and Arthur D. Little, Inc., estimates.

Table VI-19. U.S. ETHYLENE DICHLORIDE MANUFACTURERS - 1973

	Allied Chemical	American Chem. Corp.[a]	Conoco	Diamond Shamrock	Dow	Ethyl Corp.	B.F. Goodrich	Jefferson Chem. Co.[b]	PPG	Shell	Union Carbide	Vulcan Materials	Total
Capacity (million pounds per year)	650	235	1000	260	3560	810	900	70	1835	2400	300	240	12,260
Percent of total U.S. capacity	5.3	1.9	8.2	2.1	29.0	6.6	7.3	0.6	15.0	19.6	2.5	2.0	100
Production (million pounds per year)	493	177	762	195	2695	613	678	56	1394	1821	232	186	9,302
Production Value ($ million)	14.8	5.3	22.9	5.9	80.9	18.4	20.4	1.7	41.8	54.6	7.0	5.6	279.3

[a] American Chemical has been consolidated into Stauffer Chemical Corporation.

[b] Joint venture with Texaco and American Cyanamid: no longer a producer.

Sources: Directory of Chemical Producers, U.S. International Trade Commission, and Arthur D. Little, Inc., estimates.

There are twelve producers of ethylene dichloride, although the three largest manufacturers have 64 percent of domestic production capacity. Dow, Shell, and PPG Industries had 29 percent, 20 percent and 15 percent of domestic production capacity respectively in 1973. Based on reported production, the industry was operating at approximately 75 percent of capacity in 1973.

U.S. production of ethylene dichloride had an annual average growth rate of 16 percent between 1960 and 1973. Future growth by the industry is estimated to be 8-9 percent per year. The demand for ethylene dichloride depends heavily on demand for vinyl chloride which consumes greater than 85 percent of the ethylene dichloride production. Environmental pressures may reduce demand for ethylene dichloride for vinyl chloride and trichloroethylene production. In addition, the demand for ethylene dichloride as a lead scavenger may be reduced if the trend toward unleaded gasoline continues.

Methyl chloride and methylene chloride producers and related capacities are summarized in Table VI-20. There are eleven producers of methyl chloride, although four producers have 73.5 percent of total production capacity. Dow, Conoco, DuPont and Ethyl Corporation have 34.0 percent, 15.5 percent, 12.4 percent and 11.6 percent of domestic capacity respectively. The production value of methyl chloride for these eleven companies was $32.8 million in 1973, and capacity utilization was 84 percent of total domestic capacity. Since methyl chloride is principally used as a chemical intermediate, there was a high level of captive use (greater than 50 percent) in 1973.

Table VI-20. U.S. METHYL CHLORIDE AND METHYLENE CHLORIDE MANUFACTURERS - 1973

	Allied Chemical	Conoco	Diamond Shamrock	Dow	Dow Corning	DuPont	Ethyl Corp.	General Electric	Stauffer	Union Carbide	Vulcan Materials	Total
Methyl Chloride												
Capacity (million pounds per year)	25	100	25	220	35	80	75	20	15	50	2	647
Percent of total U.S. capacity	3.9	15.5	3.9	34.0	5.4	12.4	11.6	3.1	2.3	7.7	0.3	100
Production (million pounds per year)	21	84	21	185	29	68	63	17	13	42	1	544
Production Value ($ million)	1.3	5.1	1.3	11.1	1.7	4.1	3.8	1.0	0.8	2.5	0.1	32.8
Methylene Chloride												
Capacity (million pounds per year)	50	-	60	240	10	40	-	-	60	-	70	530
Percent of total U.S. capacity	9.4	-	11.3	45.3	1.9	7.6	-	-	11.3	-	13.2	100
Production (million pounds per year)	49	-	59	236	10	40	-	-	59	-	69	522
Production Value ($ million)	3.9	-	4.7	18.8	0.8	3.2	-	-	4.7	-	5.5	41.6

Sources: Directory of Chemical Producers, U.S. International Trade Commission, and Arthur D. Little, Inc., estimates

U.S. production of methyl chloride increased at an average annual rate of 15 percent between 1962 and 1972, however, since 1969 it has averaged only 4 percent growth per year. The slow rate of growth in recent years is due to uncertain demand from the tetramethyl lead end-use sector. However, a surplus of methyl chloride does not exist in the market and supplies are currently snug due to limited availability of methanol. The future of the tetramethyl lead market plus the availability of methanol will affect future growth of methyl chloride most significantly and probably will limit it to moderate to static growth.

Methylene chloride had an estimated production value of $41.6 million in 1973 with a small captive usage of approximatley 10 percent. There are seven producers with four companies having greater than 80 percent of total capacity. Capacity utilization was an estimated 98 percent in 1973.

U.S. production of methylene chloride has grown at an average annual rate of 13 percent between 1963 and 1973. This average rate has slowed during the last five years when growth of methylene chloride production declined to 12 percent per year. However, exports seem to have accounted for a large measure of this growth. Anticipated future growth for methylene chloride consumption is forecast at an average of 8 percent per year.

The producers of methyl chloroform and their related production capacities are summarized in Table VI-21. The production of methyl chloroform is high concentrated with only four domestic producers. Two companies, Dow Chemical and PPG Industries, account for 81.8 percent of U.S. production capacity with 54.8 percent and 27.8 percent of total capacity respectively.

Table VI-21. U.S. METHYL CHLOROFORM MANUFACTURERS - 1973

	Dow	Ethyl Corp.	PPG	Vulcan Materials	Total
Capacity (million lb/yr)	340	50	175	65	630
Percent of total U.S. capacity	54.0	7.9	27.8	10.3	100%
Production (million lb/yr)	244	36	126	47	453
Production value ($million)	22.0	3.2	11.3	4.2	40.7

Sources: Directory of Chemical Producers, U.S. International Trade Commission, and Arthur D. Little, Inc. estimates.

Methyl chloroform producers were operating at an estimated 71.7 percent of total capacity in 1973, with a total production value of $40.7 million.

In the past decade methyl chloroform has experienced a 15 percent average annual growth rate. Industry estimates place future growth rates at 8 percent annually, although the outlook depends upon environmental considerations. Methyl chloroform is a substitute product, in some aspects of metal cleaning, for trichloroethylene which has come under increasingly restricted use because of air pollution control regulations. If further restrictions are placed upon trichloroethylene, the demand for methyl chloroform could increase at greater than 8 percent per year assuming there are no environmental restrictions placed on methyl chloroform as well.

The domestic producers of perchloroethylene and trichloroethylene and their related capacities are shown in Table VI-22. The production of trichloroethylene is concentrated with five principal producers in the United States. PPG Industries and Dow Chemical also dominate the production of trichloroethylene with 45 percent and 24 percent of domestic production capacity respectively. The total production value for trichloroethylene was $31.8 million in 1973, and capacity utilization was approximately 73 percent.

Trichloroethylene has grown at an average annual rate of approximately 2 percent from 1963-1973. Industry estimates range from no growth to a 6 percent decline through 1977. In 1966 trichloroethylene was restricted under Los Angeles' Rule 66 as a measure to control air pollution. Since 1966, other states have passed similar legislation and producers have put off planned capacity expansions.

Table VI-22. U.S. TRICHLOROETHYLENE AND PERCHLOROETHYLENE MANUFACTURERS - 1973

	Diamond Shamrock	Dow Chemical	Ethyl Corp.	Occidental/ Hooker Chemical	PPG	Stauffer	Vulcan Materials	Total
Trichloroethylene								
Capacity (million pounds per year)	100	150	50	40	280	-	-	620
Percent of total U.S. capacity	16.1	24.2	8.1	6.5	45.2	-	-	100
Production (million pounds per year)	73	109	37	29	204	-	-	452
Production value ($million)	5.1	7.7	2.6	2.1	14.3	-	-	31.8
Perchloroethylene								
Capacity (million pounds per year)	160	290	50	50	200	70	200	1020
Percent of total U.S. capacity	15.7	28.4	4.9	4.9	19.6	6.9	19.6	100
Production (million pounds per year)	111	201	35	35	138	49	138	707
Production value ($million)	6.6	12.0	2.1	2.1	8.3	2.9	8.3	42.3

Sources: Chemical Marketing Reporter, U.S. International Trade Commission, and Arthur D. Little, Inc., estimates.

Production of *perchloroethylene* is less concentrated than that of trichloroethylene, with seven domestic producers. Three producers account for 67.6 percent of total capacity and Dow, PPG Industries and Vulcan Materials have 28.4 percent, 19.6 percent and 19.6 percent of capacity respectively. The 1973 production value of perchloroethylene was $42.3 million and estimated capacity utilization was 69 percent in 1973.

For the past decade perchloroethylene production has grown at an average annual growth rate of 8 percent. The future outlook depends upon the dry cleaning market which is expected to grow at 4-5 percent annually. If increased environmental restrictions are placed on trichloroethylene, perchloroethylene could potentially benefit as a partial replacement for trichloroethylene.

Employment in the production of the nine chlorocarbons discussed above is an estimated 6,600 employees including both direct and related production personnel.[a] The employement estimate is based on industry contacts as well as data from the *Census of Manufacturers, 1972*. The production value of the nine chlorocarbons represents 6.6 percent of the total value of shipment in SIC 2869, "Industrial Organic Chemicals, N.E.C."

Table VI-23 summarizes the principal producers of chlorocarbons, their total chemical sales in 1973 and related value of domestic production of chlorocarbons. Included is a summary of the value of various chlorocarbons as a percent of these companies' total chemical sales. For example, the combined value of production of chloroform, carbon tetrachloride, and methyl

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[a] Based on 100,400 employees engaged in the production of industrial organic chemicals.

Table VI-21 U.S. CHLOROCARBON INDUSTRY - 1973

Company	Total Chemical Sales (1973) ($ million)	Value of Chlorocarbon Production[a] ($ million)	% of Total Chemical Sales	Value of Chlorocarbon Production Excluding Ethylene Dichloride ($ million)	% of Total Chemical Sales	Value of chloroform, carbon tetrachloride, methyl chloroform ($ million)	% of Total Chemical Sales
Allied Chemical	1,114	22.0	2.0	7.2	0.6	2.0	0.2
American Chemical[b]	621	11.2	1.8	5.9	1.0	0	0
Conoco	221	28.0	12.7	5.1	2.3	-	-
Diamond Shamrock	454	24.6	5.4	18.7	4.1	1.0	0.2
Dow Chemical	2,250	174.9	7.8	94.0	4.2	40.4	1.8
Dow Corning	NA	2.5	NA	2.5	NA	-	-
DuPont	4,250	34.0	0.8	34.0	0.8	20.8	0.5
FMC	745	11.9	1.6	11.9	1.6	11.9	1.6
Ethyl Corp.	499	49.5	9.9	31.1	6.2	[illegible].2	0.6
General Elec.	NA	1.0	NA	1.0	NA	-	-
B.F. Goodrich	452	20.4	4.5	-	-	-	-
Jefferson Chemical	NA	1.7	-	-	-	-	-
Occidental	1,080	4.2	0.4	4.2	0.4	-	-
PPG	440	82.2	18.7	40.4	9.2	11.3	2.6
Shell Oil	748	59.2	7.9	4.6	0.6	-	-
Stauffer	621	29.4	4.7	29.4	4.7	21.0	3.4
Union Carbide	2,400	9.5	0.4	2.5	0.1	-	-
Vulcan Materials	62	29.0	46.8	23.4	37.7	9.5	15.3

[a] Includes methyl chloride, methylene chloride, chloroform, carbon tetrachloride, methyl chloroform, perchloroethylene, trichloroethylene, ethylene dichloride, ethyl chloride.

[b] American Chemical has been consolidated into Stauffer Chemical Corporation.

Sources: Corporate annual reports and Arthur D. Little, Inc. estimates.

chloroform range from 0.2 percent of chemical sales for Allied Chemical to 15.3 percent of chemical sales for Vulcan Materials.

Vinyl chloride monomer (VCM) is produced by a total of ten companies with capacity, as of June 1974, of 6-8 billion pounds per year. There is considerable concentration in the industry as the three largest firms control about 56 percent of the capacity while the five largest control nearly 80 percent.

All but two of the VCM manufacturers produce the product by dehydrochlorinating (removing hydrogen chloride from) dry ethylene dichloride (EDC). This process accounts for 92 percent of the VCM capacity. The remaining capacity at two other plants produces VCM by adding hydrogen chloride to acetylene in a reactor. This latter process is the oldest commercial process for producing VCM but it has been gradually phased out because economics favor ethylene as a raw hydrocarbon feedstock over acetylene.

Over the last 10 years the production of VCM has grown at an annual rate of about 13 percent from a level of 1.6 billion pounds in 1964. The most phenomenal growth occurred during the latter part of the 1960's when production increased at a rate of over 18 percent per year. Since 1970 the rate of growth has been less than 9 percent per year.

In 1975, PVC homopolymer and copolymer-resins were produced by 21 companies at 38 plants (see Table VI-24). Of the 21 companies, between two and six produced only copolymers at a total of 11 plants. As was the case with the VCM industry, a few firms account for much of the total capacity. Five companies control approximately 51 percent of total industry capacity while the nine largest account for about 71 percent.

Table VI-24. PRODUCING COMPANIES, PLANT LOCATION, AND CAPACITIES-PVC HOMOPOLYMER RESINS

Producing company	Plant location	Capacity-May, 1975 (millions of pounds/year)
Air Products, Inc.	Calvert City, Kentucky	135
	Pensacola, Florida	75
Borden, Inc.	Illiopolis, Illinois	140
	Leominster, Massachusetts	180
Continental Oil Co.	Aberdeen, Mississippi	260
	Oklahoma City, Oklahoma	220
Diamond Shamrock Corp.	Delaware City, Delaware	115
	Deer Park, Texas	270
Ethyl Corp.	Baton Rouge, Louisiana	180
Firestone Tire Co.	Perryville, Maryland	230
	Pottstown, Pennsylvania	270
General Tire Co.	Ashtabula, Ohio	125
	Point Pleasant, W. Va.[a]	50
Georgia-Pacific Corp.	Plaquemine, Louisiana	220
B. F. Goodrich Co.	Avon Lake, Ohio	260
	Henry, Illinois	220
	Long Beach, California	115
	Louisville, Kentucky	145
	Pedricktown, New Jersey	140
Goodyear Tire Co.	Niagara Falls, New York	100
	Plaquemine, Louisiana	105
Great American Chemical Corp.	Fitchburg, Massachusetts	70
Keysor-Century Corp.	Saugus, California	35
Monsanto Co.[b]	Springfield, Massachusetts	70
Occidental Petroleum Corp. (Hooker Chemical)	Burlington, New Jersey	168
	Hicksville, New York	15
Pantasote Co.	Passaic, New Jersey	60
	Point Pleasant, W. Va.[a]	50

Source: EPA, details on following page.

Table VI-24 (cont.) PRODUCING COMPANIES, PLANT LOCATION, AND CAPACITIES-PVC HOMOPOLYMER RESINS

Producing Company	Plant Location	Capacity-May, 1975 (millions of pounds/year)
Robintech, Inc.	Painesville, Ohio	250
Shintech, Inc.[c]	Freeport, Texas	220
Stauffer Chemical Co.[d]	Delaware City, Delaware	175
	Long Beach, California	150
Tenneco Chemicals, Inc.	Burlington, New Jersey	165
	Flemington, New Jersey	70
	Pasadena, Texas	240
Union Carbide Corp.	South Charleston, W.Va.	160
	Texas City, Texas	300
Uniroyal, Inc.	Painesville, Ohio	108
TOTAL		5,861

a. 100 million tons per year plant at Point Pleasant.

b. Monsanto has announced it will close its plant by the end of 1975.

c. Shintech is a joint venture of Robintech and Shin-Etsu Chemical Industry Company Ltd. of Tokyo.

d. Stauffer purchased remaining 50 percent interest of the American Chemical Co. from Arco in 1974.

Sources: Chemical Marketing Reporter, May 20, 1974; Modern Plastics, January 1975, p. 58; Non-confidential data supplied by industry under Section 114 of the Clean Air Act.

There is a limited amount of vertical integration within the PVC industry from the production of EDC through resin processing. Two companies produce all four products (i.e., EDC, VCM, PVC homopolymer, PVC copolymer) while another five companies manufacture three of the four products. In addition, 11 companies produce two of the four products.

Over the last 10 years PVC consumption has grown at an annual rate of around 11 percent, from a level of 1.6 billion pounds in 1964 to roughly 4.7 billion pounds in 1974. However, the growth has been somewhat erratic. From 1966 to 1971 PVC consumption grew at a nine percent annual rate, but in 1972 consumption increased by more than 27 percent over the 1971 level. Consumption in 1973 rose another 9.7 percent before leveling off in 1974.

The lack of detailed financial information for privately held corporations and profit data by vinyl chloride and polyvinyl chloride output for publicly held firms make an assessment of the impact of a ban on vinyl chloride difficult. For 25 firms, dependency on vinyl chloride and polyvinyl chloride production can be approximated by relating estimated vinyl chloride and polyvinyl chloride sales to total sales (Table VI-25). It should be recognized, however, that the estimated percentage of vinyl chloride and polyvinyl chloride sales are not necessarily the same as the estimated percentage of profits. Based on the information on sales, three of the 25 firms are judged to be highly dependent upon vinyl chloride and polyvinyl chloride production, [Pantasote (19 percent), Great American Chemical Corporation (43 percent) and Robintech (68 percent)].

Table VI-25. ESTIMATED DEPENDENCE OF MANUFACTURERS ON PVC SALES

Firm	Capacities (Millions of Pounds Per Year)			Revenues Dependent on PVC[a] (Millions of 1973 Dollars)				Total 1973 Sales Revenues	Percent sales Dependent on PVC[b]
	Ethylene Dichloride	Vinyl Chloride	Polyvinyl Chloride	Ethylene Dichloride	Vinyl Chloride	Polyvinyl Chloride	Total		
Air Products and Chemical	0	0	210	-	-	31.50	31.50	398.9	8
Allied Chemical Corporation	650	340	0	3.00	-	17.10	20.10	1501.0	1
Borden, Inc.[c]	0	0	320	-	-	64.00	64.00	2554.0	3
Continental Oil	1000	730	480	2.35	12.5	72.00	86.85	4510.0	2
Diamond Shamrock	110	0	385	-	-	55.50	55.50	667.1	8
Dow Chemical[d]	3560	1220	150	81.62	53.50	22.50	157.62	3067.9	5
Ethyl Corporation	810	420	180	4.32	12.0	27.00	43.32	713.7	6
Firestone Tire Company	0	0	500	-	-	75.00	75.00	3154.9	2
General Tire	0	0	175	-	-	25.88	25.88	1380.0	2
Georgia Pacific	0	0	220	-	-	33.00	33.00	2228.7	1
B.F. Goodrich Company	1000	1000	880	-	6.00	132.00	138.00	1661.0	8
Goodyear Tire Company	-	-	205	-	-	30.75	30.75	4675.3	1
W. R. Grace[d]	-	-	300	-	-	45.00	45.00	2807.8	2
Great American Chemical Corp.	-	-	70	-	-	6.00	6.00	14.04	43
Keysor-Century	-	-	35	-	-	5.25	5.25	NA	NA
Monochem, Inc.	-	300	-	-	15.00	-	15.00	NA	NA

Source: EPA, based on contractors' reports and industry contacts. See notes on following page.

Table VI-25 (cont.). ESTIMATED DEPENDENCE OF MANUFACTURERS ON PVC SALES

Firm	Capacities (Millions of Pounds Per Year) Ethylene Dichloride	Vinyl Chloride	Polyvinyl Chloride	Revenues Dependent on PVC[a] (Millions of 1973 Dollars) Ethylene Dichloride	Vinyl Chloride	Polvvinyl Chloride	Total	Total 1973 Sales Revenues	Percent sales Dependent on PVC[b]
Monsanto	-	-	70	-	-	10.50	10.50	2648	negligible
Morton - Norwich[d]	-	-	150	-	-	22.50	22.50	607	6
Occidental Petroleum	-	-	183	-	-	26.45	26.45	1980.4	3
Pantasote	-	-	108	-	-	16.20	16.20	86.79	19
PPG Industries	1835	800	-	21.80	40.0	-	61.80	1512.6	4
Robintech	-	-	250	-	-	250	37.50	55.51	68
Shell Oil Company	2365	1600	-	-	70.0	-	70.00	5749.6	1
Stauffer Chemical Company	300	170	325	-	1.00	48.75	49.75	NA	NA
Tenneco Chemical Inc.	-	255	415	-	1.00	35.25	36.25	3940.0	1
Union Carbide	300	-	460	-	-	60.00	69.00	3938.8	2
Uniroyal Inc.	-	-	108	-	-	16.20	16.20	2090.0	1
Vulcan Materials	240	-	-	13.50	-	-	13.50	325.3	4

a. Estimated on the following assumptions: \$.05/lb for EDC and VC; \$.15/lb for general purpose PVC; it takes 1.58 lbs. of EDC to make a lb of VC; it takes 1 lb of VC to make a lb of PVC; operating rate 100 percent; and intra-company transfer of EDC and for VC revealed in the price of end product. Ex. Allied Chemical Corp.
[600-(342 x 1.58)] x \$.05 + 342 x \$.05 = 3.00 + 17.10 = 20.10

b. Total Revenues Dependent on PVC + Total 1973 Sales Revenues.

c. Revenues were adjusted to reflect the price of the copolymer (vinyl acetate) produced here. Price of that PVC copolymer was \$.20/lb.

d. Plant capacity was not known. For each plant a 150 million pound/year capacity was assumed.

Source: EPA, based on contractors' reports and industry contacts.

The direct employment impacts of a vinyl chloride and polyvinyl chloride ban are not known. However, estimates of total vinyl chloride and polyvinyl chloride plant employment are available, and indicate that 1,000 people are employed in vinyl chloride production. Banning vinyl chloride production would end the need for the services of these people. Although many skills used in vinyl chloride production are readily transferable to other industries, the extent of this transfer availability is not known, and it would not be immediate.

In the polyvinyl chloride industry, approximately 5,000 workers are employed. As in the vinyl chloride industry, many workers' skills are transferable. But, again, the degree to which these transfers are available or will occur is not known.

For vinyl chloride plants, the immediate regional impacts of a production ban would be primarily upon the areas of southeastern Texas and southern Louisiana where 12 out of the 15 vinyl chloride plants are located. In certain instances, vinyl chloride output goes to other regions. In these cases, multiplier impacts in terms of decreased output, unemployment, and lower income could be expected.

For polyvinyl chloride plants, the immediate impact of a production ban would be more dispersed geographically. Although some polyvinyl chloride plants are located in the southeast Texas/southern Louisiana area, most are located in the eastern part of Delaware, New Jersey, New York and Massachusetts. As in the vinyl chloride case, multiplier impacts would occur.

The indirect impacts of a ban on vinyl chloride and polyvinyl chloride production would be primarily upon the raw material suppliers (ethylene dichloride producers send about 78 percent of their output to vinyl chloride and polyvinyl chloride markets) and product output receivers (fabricators).

For the vinyl chloride and polyvinyl chloride fabricating business, it is estimated that the number of fabricators is 8,000. It is not known how many of the 8,000 are independent or how many are affiliated with larger firms. The viability of the fabricator has not been analyzed. To the extent that those firms are solely dependent on vinyl chloride and polyvinyl chloride input, the occurrence of a significant impact with a vinyl chloride and polyvinyl chloride ban is likely.

In the fabrication of PVC, total direct and indirect related employment is estimated to be 1.7 to 2.2 million jobs. This amounts to over 1 percent of the 1972 labor force. (This figure includes not only persons employed by fabricating companies, but also persons employed in utilization of the fabricated products.

3. Chemical Intermediates

The principal chemical intermediate applications for the chlorocarbons and fluorocarbons under evaluation (excluding vinyl chloride which has been treated separately) are for the production of tetramethyl and tetraethyl lead, silicones, vinylidene chloride, ethylene amines, and fluorocarbon resins.

Tetramethyl and tetraethyl lead are produced from methyl chloride and ethyl chloride respectively. The principal producers and related capacities of tetraethyl and tetramethyl lead are summarized in Table VI-26. DuPont and Ethyl Corporation are the major producers with over 80 percent of total industry capacity, and PPG Industries and Nalco Chemical make up the balance of production capacity. Only the production of tetraethyl lead is reported. Therefore, a reliable estimate of capacity utilization is not available because capacity estimates include production capacities for both tetramethyl and tetraethyl lead.

Historical growth has been 4 percent per year from 1967-1973. No future growth is expected because of environmental pressures on leaded gasoline. Some industry sources have estimated that production would decline 13 percent per year through 1978, if catalytic exhaust converters are used on new automobiles.

The principal producers of silicones (produced from methyl chloride) are Dow Corning, General Electric, Stauffer, and Union Carbide. Capacity estimates and production figures are not available; therefore, at this time it is difficult to accurately assess the value of production of silicones in relation to these companies' total sales. Silicones are

Table VI-26. U.S. TETRAETHYL AND TETRAMETHYL LEAD MANUFACTURERS--1973

	DuPont	Ethyl Corp.	Nalco Chemical	PPG	TOTAL
Capacity (million lb/yr	340	350	40	100	830
Percent of total U.S. capacity	41.0%	42.2%	4.8%	12.0%	100%
Production (million lb/yr)	139.4	149.0	17.0	42.4	353.3 (TEL only)

Sources: Chemical Marketing Reporter, U.S. International Trade Commission, and Arthur D. Little, Inc., estimates.

principally used in the production of specialty fluids, elastomers, and resins. Production for resin and elastomer uses is reported, but production for the principal end use, silicone fluids, is not reported. Reported production for resins and elastomers was 18.4 and 37.0 million pounds in 1973, with production values of $35.3 and $82.1 million, respectively.

Vinylidene chloride is produced from ethylene dichloride, and in 1971 Dow began production of vinylidene chloride from methyl chloroform. The principal producers are Dow, PPG Industries, and Vulcan Materials. Vinylidene chloride is principally used to produce polyvinylidene chloride (PVDC) for use in coating and films (e.g., Saran Wrap), and as a minor component in certain copolymer resins.

Ethylene amines are produced from ethylene dichloride. Estimated production was 64 million pounds in 1973. Total capacity (based on monoethylenediamines) is 90 million pounds, and the principal producers, Dow and Union Carbide having one third and two-thirds of total capacity, respectively. Ethylene amines are used principally in fungicides and as chelating agents. Recent growth was 7 percent per year; however, future growth is expected to decline to 3 percent per year.

There are a number of fluorocarbon resins and elastomers, although it is estimated that polytetrafluoroethylene (PTFE) is the major fluorocarbon plastic produced. Manufacturers include DuPont (Teflon), Allied, Pennwalt, and ICI. Production of PTFE was 14 million pounds in 1973.

4. Propellants

a. Aerosol Cans - The aerosol can market should be viewed as part of the larger metal can industry. The rationale for this broader industry definition is the fact that the leading producers of aerosol containers and related products are horizontally integrated and produce metal cans for most of the wide variety of end-use segments in the overall industry.

The Metal Can Industry - The metal can industry is the largest of all packaging sectors in the United States. The value of metal cans shipped in 1973 was about $4.9 billion. (This compares to about $4.4 billion for corrugated containers, the second largest packaging sector.) Table VI-27 shows a breakdown of U.S. metal can shipments by end-use. Here it can be seen that there were about 83.4 billion units shipped in 1973, and that the beverage market was the largest sector, accounting for about 50 percent of this total.

Metal can industry shipments have increased from 1968 to 1973 at about 5 percent per year. The beverage can market has been the fastest growing sector in the industry with a 9.5 percent per year growth rate over this period. Factors contributing to this growth are the beverage can's superior convenience, filling and handling characteristics, compared to the glass bottle. In contrast to the beverage can market, the food can market has grown at only 1.5 percent per year from 1968 to 1973. Although canning is still the major food processing method, the food can market is expanding at a lower rate of growth due in part to the impact of newer and faster growing frozen food processing techniques. The general packaging can market consists of relatively mature end-uses such as antifreeze (heavily impacted by plastic can penetration) paint and motor oil. This market has

Table VI-27. U.S. METAL CAN SHIPMENTS - 1973

	Billion units	Percent of total shipments
Beverage cans		
Beer	24.0	28.8
Soft drink	17.7	21.2
Total beverage cans	41.7	50.0
Food cans		
Vegetables & juices	10.5	12.6
Fruits & juices	5.8	6.9
Meat & poultry	1.8	2.1
Fish & seafood	1.7	2.0
Evaporated & condensed milk and other dairy products	1.5	
Coffee	0.8	
Baby food	0.7	13.4
Lard & shortening	0.4	
Miscellaneous foods	7.8	
Total food cans	31.0	37.0
General packaging cans		
Aerosols	3.0	3.6
Motor oil	0.8	1.0
Paint	0.8	1.0
Other	2.3	2.8
Total general packaging cans	6.9	8.4
Pet food	3.8	4.6
Total metal can shipments	83.4	100.0

Sources: Can Manufacturers Institute, U.S. Department of Commerce - Current Industrial Reports Series M34D, and Arthur D. Little, Inc., estimates.

grown at less than 1 percent per year over the five year period ending in 1973. (One exception to the mature growth characteristics of the general packaging can market is the aerosol sector which is discussed in the following section.)

The Aerosol Container Market - The value of aerosol cans shipped in 1973 was about $190 million which is about 3.9 percent of the total value of shipments in the overall metal can industry. As shown in Table VI-27 there were about 3.0 billion aerosol cans shipped in 1973, or about 3.6 percent of total industry shipments. The difference between the aerosol industry's percentage of total value of shipments compared to its percentage of total units shipped reflects the fact that aerosol containers have a higher average unit value than the average value of cans in the industry as a whole. This is due to the fact that the aerosol container is a relatively complex and expensive package, which is justified only by its great convenience value in many diverse applications. Table VI-28 shows a breakdown of 1973 aerosol container shipments by end-use. The two largest aerosol applications are deodorants/anti-perspirants and hair care products with nearly 20 percent and 16 percent respectively of the total aerosol container market. About 85 percent of the personal product applications use a fluorocarbon type propellant. Thus, this sector, which accounts for half of the total aerosol market in terms of units shipped, has the greatest potential for economic impact under a ban of fluorocarbon use. About 15-20 percent of household products applications and about 10 percent of the miscellaneous category also currently use fluorocarbon type propellants.

Table VI-28. U.S. AEROSOL CONTAINER SHIPMENTS - 1973

	Million units	Percent of total shipments
Personal products		
Deodorants & anti-perspirants	580	19.6
Hair care products	470	15.9
Shaving lather	170	5.7
Colognes and perfumes	140	4.7
Medicinals & pharmaceuticals	70	2.4
Other	70	2.4
Total personal products	1,500	50.7
Household products		
Cleaners	210	7.1
Room deodorants & disinfectants	170	5.7
Laundry/starch products	160	5.4
Waxes & polishes	100	3.4
Other	40	1.4
Total household products	680	23.0
Miscellaneous		
Coatings and finishes	270	9.1
Insect sprays	140	4.7
Industrial products	120	4.1
Foods	110	3.7
Automotive products	90	3.0
Other	50	1.7
Total miscellaneous	780	26.3
Total aerosol container shipments	2,960	100

Source: Chemical Specialties Manufacturers Association, Modern Packaging and Arthur D. Little, Inc., estimates.

The aerosol container market has been the second fastest growing market in the overall metal can industry (next to the beverage can market) with a 6.5 percent growth rate from 1968 to 1973. The miscellaneous products category has grown the fastest since 1968, at about 8.5 percent per year. Growth in this category has been led by industrial and automotive applications with more than 30 percent and 11 percent per year growth rates respectively. The large personal products sector has grown at nearly 5 percent per year over this time frame. Growth in this sector has been led by deodorant/anti-perspirant applications (12 percent per year) and colognes/perfumes (5 percent per year). These growth sectors have been offset to some extent by the more mature hair care products sector which has actually declined by nearly 1 percent per year over this time period. Finally, the household products category appears to be another mature sector with slightly less than 2 percent per year growth from 1968 to 1973.

Industry Structure - The metal can industry is made up of about 100 companies that operate approximately 350 plants. Three-quarters of total can shipments are supplied by merchant can suppliers and about one-quarter by companies that produce cans for their own use. The can industry is one of the most concentrated of all packaging industries. The two leading merchant can companies, American Can and Continental Can, accounted for roughly two-thirds of all merchant can sales in 1973. National Can and Crown Cork and Seal, the third and fourth leading merchant can companies, accounted for an additional 15 percent of merchant can sales. Thus, four companies accounted for about 80 percent of total merchant can sales in 1973. The leading merchant can companies are typically fully horizontally integrated in the metal can industry and produce metal cans for most of the end-use sectors mentioned previously, including aerosols. Further, many of these companies extend beyond the can industry itself and are involved in other packaging and nonrelated activities such as glass container manufacture, converted paper and plastic products production, and the manufacture of various consumer products. Can manufacture for fluorocarbon-related aerosols is less than 10 percent of the sales of these leading merchant can companies.

In addition to the major can companies, however, several smaller aerosol can manufacturers exist in the merchant can market. Although the sales of these smaller companies represent only a small share of the total aerosol can market, these companies do depend to a much greater degree on aerosol can manufacture than do the leading can manufacturers. Examples of this type of company are Peerless Tube Company and Apache Container Corporation. Further work will be required in order to identify and assess regulatory effects on these smaller companies whose aerosol container sales represent a substantial portion of total company sales.

In addition to the merchant can sector, at least forty companies manufacture cans for their own use. Coors, Schlitz and Anheuser Busch in the beer industry and Campbell Soup, Carnation, Borden and H.J. Heinz in the food industry are examples of companies that are backward integrated to can manufacture. Also, R.J. Reynolds and Kaiser Aluminum are forward integrated to can manufacture. Sherwin Williams is the only known aerosol can manufacturer that produces cans for its own use.

Related Container Industries - About 94 percent of the aerosol product market is packaged in metal cans. Cans are preferred primarily for their high barrier and safety characteristics. Glass and plastic containers account for about 5 percent and 1 percent of the aerosol market respectively. Total glass container shipments in 1973 were about 39.5 billion units with a value of $2.3 billion. Total plastic bottle shipments were about 7.4 billion units in 1973 with a value of $514 million. Thus, the glass and plastic aerosol market segment makes up a very small part of these related container industries.

b. Aerosol Fillers and Marketers

In addition to the manufacture of aerosol-related hardware, i.e. caps, valves and canisters, a major industry exists around the filling process for aerosol products. In 1973 the estimated sales volume of firms engaged in aerosol filling was on the order of $2.2 billion at the manufacturers' level. This estimate includes sales of the industry's two major segments, captive fillers which are generally subsidiaries or divisions of companies whose primary business is the marketing of aerosols and other products, and contract fillers whose prime business is filling aerosol products to the specifications of aerosol marketers. Industry sources estimate that contract fillers account for approximately 60 percent of the total units filled. For 1973, based on industry estimates of 2.9 billion units filled, contract fillers filled approximately 1.74 billion units while captive producers processed very nearly 1.16 billion units.

Table VI-29 summarizes the estimated sales and employment in the aerosol industry. Our employment estimates include only those employees directly involved in the filling of aerosol products and their directly related support people, i.e. quality control, warehousing, distribution, and purchasing. We estimate directly related support personnel to approximate 10 percent of the total direct manufacturing employees. We have not included in our estimates, employment for those jobs which are indirectly related to aerosol filling. These include sales, marketing, administrative, and other corporate overhead employees and, if included in employment estimates, could approximately double the figure shown in Table VI-29 to nearly 30,000 employees.

TableVI-29. 1974 AEROSOL FILLING INDUSTRY SALIENT STATISTICS

Filler type	Units filled (millions)	Sales[a] (millions)	Employees[b]
Contract	1,740	250	8,500
Captive	1,160	2,000	6,000
Totals	2,900	2,250	14,500

[a] Sales at manufacturer's level

[b] Employment directly related to aerosol filling.

Source: Arthur D. Little, Inc., estimates based on communications with the industry.

The exact number of directly and indirectly related employees is extremely difficult to estimate since it varies widely with the efficiency of the filler, the nature of the business, i.e. strictly a filler or a combination marketer/filler and the geographical scope of operations. Contract fillers, with their operations generally limited relative to marketer/fillers, typically have fewer support people, especially in marketing, sales, and corporate administrative positions, since the nature of the business does not allow or require their existence. The marketer/fillers, however, whose operations frequently involve widespread distribution of aerosol and other products, typically employ marketing and administrative personnel, only part of whose responsibility involves aerosol products, but whose number equals or exceeds the number directly involved in aerosol filling.

An important distinction to note is the difference in the role of the contract filler when compared to that of the marketer with a captive filling operation. The contract filler provides aerosol filling capabilities for those marketers who do not have a product line which justifies investment in captive aerosol filling capacity. With relatively few exceptions, contract fillers are small in size, large in number and rather regionally oriented in the scale of their operations. Figure VI-3 shows graphically the fact that the number of firms with filling capacities less than 10 million units per year accounts for nearly 50 percent of the total number of firms, but that their total aggregate capacity is only 6 percent of total industry capacity. Conversely, the firms with filling capacities in excess of 200 million units per year account for only 3 percent of the total number of firms, but over 30 percent of the industry filling capacity.

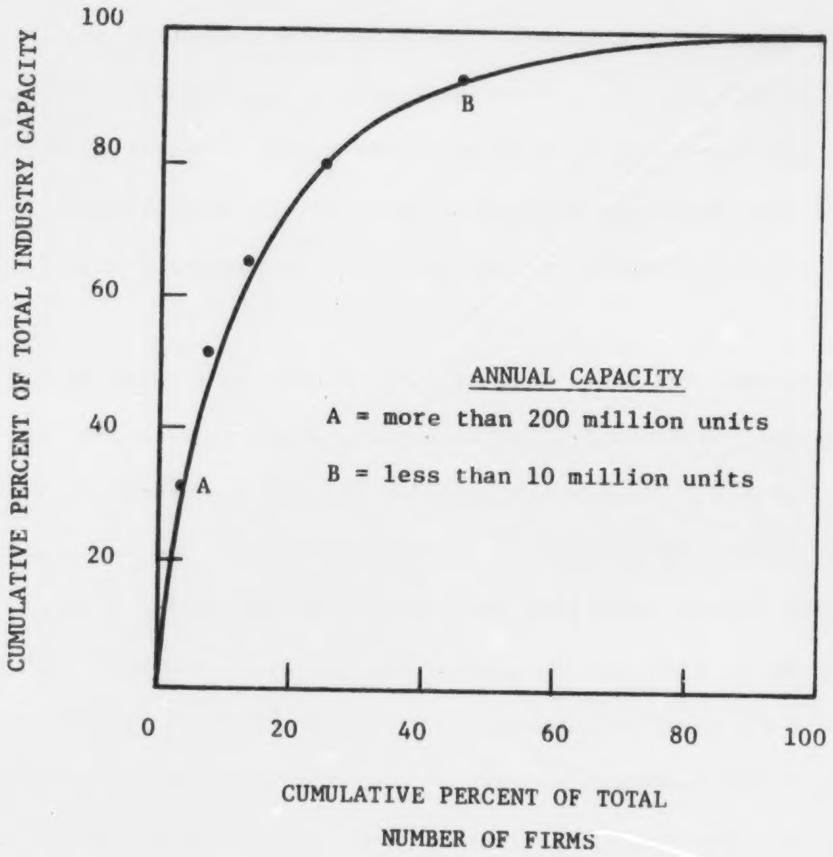

Figure VI-3. Aerosol Filling Industry Capacity as a Function of Number of Fillers

Sources: Aerosol Handbook and Arthur D. Little, Inc., estimates.

Many of the contract fillers, especially the smaller more regionally oriented firms, rely on one or two major accounts for the bulk of their business, and hence, are vulnerable to the loss of an account going to captive production--or could be vulnerable to costly process changeovers to alternate propellants or delivery systems if a fluorocarbon propellant ban affected the products of their major customer. The larger contract filling firms such as Aerosol Techniques, Inc., Peterson/Puritan, (subsidiary of CPC International), and Barr-Stalfort have much more widely diversified operations from both a geographic and product-mix standpoint, and would not be as vulnerable to limitations on fluorocarbon use or changes in their customer base.

Many aerosol marketers have captive filling operations as the result of their aerosol business growing to a point where captive filling is economically justified. Captive filling for the marketer represents a backward integration step from the prime business of producing and marketing products which utilize aerosol packaging for consumer appeal and/or effective product use. While it is difficult to generalize, potential economic dislocation in terms of lost sales and unemployment from a potential fluorocarbon ban should affect the marketers of aerosol products with captive filling operations less than the contract fillers. Since the marketers' prime concern is the sale of personal care, household, or other products, a ban on fluorocarbon propellants would most likely mean a switch toward an acceptable propellant or package, rather than leaving the business entirely. Thus, one would expect a shift to alternative products or propellants in the event of a fluorocarbon propellant ban. The dislocation in terms of employment and industry segment sales would be determined by the extent to which alternate products would be accepted by the consumer.

The scope of this study did not allow for a detailed analysis of the aerosol filling industry. Relatively little published information exists regarding its operations and characteristics. A key area for further consideration is the actual operating performance and flexibility of representative fillers, as these factors would be influenced by a possible fluorocarbon propellant ban. Many of both the fillers and marketers contacted have begun initial development of alternate propellant systems or products and, at this point, do not anticipate debilitating changeover costs in adapting current filling capacity to new propellants if a fluorocarbon ban is enacted. However, this is an extreme generalization which should be clarified through further effort aimed at identifying and quantifying specific impacts on a representative sample of fillers, both contract and captive. Also, since certain fluorocarbon aerosol products do not presently have acceptable alternatives, certain firms may be more adversely impacted depending on the company's product mix.

c. Valves

The estimated value of valves used in aerosol containers produced in the United States was approximately $60 million in 1973. The major producer of valves is Precision Valve Corporation with an estimated 50 percent of the total market. There are an additional nine valve producers that supply the aerosol industry, based on a recent survey of the Chemical Specialties Manufacturers Association. Employment among the valve producers is an estimated 2,000, based on industry contacts.

5. Air Conditioning and Refrigeration

The air conditioning (A/C) and refrigeration industry is a major consumer of fluorocarbons for use as refrigerants in air conditioning and refrigeration systems. The air conditioning and refrigeration industry is important both in the residential sector as well as in the industrial and commercial sectors of the U.S. economy for atmospheric temperature controls and for maintaining the quality of many products ranging from food to drugs. Refrigeration is important in such industrial sectors as food distribution, chemicals and pharmaceuticals, computer systems, electronics, aerospace and optics. The fluorocarbon refrigerants play an important role in the air conditioning and refrigeration industry. The industry has been built around the use of fluorocarbon refrigerants because of their desirable low toxicity and low flammability combined with excellent heat transfer properties. There are alternate refrigerant materials available, however, they are used to an extremely limited degree because they do not equal the physical properties of fluorocarbons. As a result, the air conditioning and refrigeration industry is highly dependent on fluorocarbon refrigerants, and limitations on the use of fluorocarbon refrigerants would significantly alter the present air conditioning and refrigeration systems. In order to develop new equipment utilizing alternative refrigerants, the industry would require a number of years to redesign equipment, build prototypes, test and retool production facilities, and achieve a high level of production capability. In addition, the impact on the existing equipment would be severe. Alternative refrigerants cannot be used interchangeably, because existing equipment has been specifically designed to utilize fluorocarbon refrigerants.

The related level of business activity in the refrigeration industry is summarized in Table VI-30. Industry employment and payroll data are included. The data presented include heating equipment as well as air conditioning and refrigeration equipment, and it is estimated that heating equipment accounts for approximately 20 percent of the total value of shipments. These employment estimates only consider direct employment related to the manufacture of refrigeration equipment and components for refrigeration equipment such as heat transfer equipment, compressors, and condensers. Indirect employment, including refrigeration equipment contractors, sales and service personnel and others, and direct employment, totaled an estimated 525,000 employees in 1972. The indirect employment impact has been determined through use of an employment multiplier analysis based on the Input/Output Structure of the U.S. Economy, 1967, U.S. Department of Commerce. This analysis has been feasible because of the well-defined nature of the refrigeration industry in the U.S. Census of Manufacturers 1972.

The major air conditioning/refrigeration equipment manufacturers are summarized in Table VI-31. The majority of these companies are highly dependent on the air conditioning/refrigeration industry, although major companies, including the automotive companies and large appliance manufacturers, such as General Electric and Westinghouse, are less dependent on the air conditioning/refrigeration industry. The table summarizes the companies' total sales, their relative profitability, and their dependence on the air conditioning and refrigeration business as a function of their total sales.

Table VI-30. U.S. REFRIGERATION INDUSTRY - 1972

	Value of shipments ($million)	Total employees		Production workers	
		Number (thousand)	Payroll ($million)	Number (thousand)	Payroll ($million)
Refrigeration and heating[a] Equipment (SIC 3585)	7033.1	149.9	1433.9	111.9	973.8
Heat transfer equipment	1540.7				
Unitary air conditioners	1171.2				
Commercial refrigeration	477.0				
Compressors	1064.4				
Condensors	142.6				
Room A/C and dehumidifiers	650.8				
Other refrigeration and A/C equipment	551.9				
Other	1434.5				
Household refrigerators and Freezers (SIC 3632)	1610.5	32.1	287.3	27.0	220.9
Household refrigerators	1192.0				
Home and farm freezers	213.1				
Other	205.4				

[a] Data includes heating equipment which represents approximately 20 percent of total value or shipments in SIC 3585.

Source: U.S. Department of Commerce Census of Manufacturers, 1972.

Table VI-31. AIR CONDITIONING/REFRIGERATION EQUIPMENT MANUFACTURERS - 1973

Company	Total 1973 sales ($million)	Net income percent of sales	A/C and refrigeration as percent of total sales	Major activity
Borg Warner (York)	1,546.8	4.6%	19%[a]	A/C
Carrier Corporation	876.7	4.6	85	A/C
Chrysler (FY ending 10/31/73)			<2	A/C
Copeland (FY ending 9/30/73)	186.5	5.3	95+	Parts
Fedders (FY ending 8/31/73)	338.4	3.1	69	A/C, R
Ford	23,015.1	3.9	7[b]	A/C, R
General Electric	11,573.5	5.1	N/A	A/C, R
General Motors	35,798.3	6.7	N/A	A/C, R
McGraw-Edison	821.0	4.0	41[c]	A/C
Tecumseh Products	524.4	5.6	70	Parts
Trane Company	317.4	5.0	95+	A/C
Weil-McClain	150.7	7.5	37[d]	A/C
Westinghouse	5,702.3	2.8	16[c]	A/C, R
Whirlpool	1,637.0	5.3	38	A/C
White Consolidated	825.6	4.2	N/A	A/C, R
Addison Products Co.	N/A	N/A	-100	A/C, R
Dunham-Bush, Inc. (Subs. of The Signal Companies)	$75 - 100	N/A	80-90	A/C, R
Lennox Industries Inc	N/A	N/A	<10	A/C
Hussman Refrigerator (Subs. of Pet Inc.)	150	N/A	50	R

[a] Includes building products

[b] Includes tractors, other appliances and electronic items

[c] Includes all U.S. consumer goods

[d] Includes heating equipment

Sources: Corporate annual reports, and Arthur D. Little, Inc.

The industry experienced rapid growth during the 1960's as the air conditioning and refrigeration industry developed, however, the air conditioning and refrigeration industry has been experiencing lower growth in recent years. Because of lower growth, increased competition, and the economic downturn in 1974, the profitability for a number of companies in the air conditioning and refrigeration business has deteriorated. For example, Borg Warner's York subsidiary experienced a loss in 1974. In addition, Carrier Corporation's level of profitability in the A/C and refrigeration business also deteriorated, and its pretax margin as a percent of sales dropped from 8.4 percent in 1973 to 0.9 percent in 1974. These examples point out the profitability problems in the industry and suggest potential limited financial capability in view of the massive effort that would be necessary for the industry to convert their air conditioning and refrigeration products to alternative refrigerants.

6. Foam Blowing Agents

Fluorocarbons are used extensively as blowing agents in the manufacture of both rigid and flexible polyurethane and polystyrene foams. Much smaller amounts are used for polyolefin foams.

The most commonly used fluorocarbon is F-11 which accounts for approximately 80 percent of all fluorocarbon used for this application. Approximately 25 percent of the F-11 produced is used as a foam blowing agent. A summary of fluorocarbon usage in each of the foam categories was presented in Table IV-9.

Principal raw materials used in the production of polyurethane foam are polyether and polyester polyols. In 1973, 1.16 billion pounds of polyether and polyester polyols were used in the production of polyurethane foam, and sales of these raw materials totaled $190 million. The major producers of polyether polyols are BASF Wyandotte Corporation, Dow Chemical, Jefferson Chemical Company (owned by Texaco), Olin Corporation and Union Carbide Corporation. These five account for over 80 percent of production. The balance is accounted for by a large number of smaller producers. Most producers of polyether polyols also produce polyester polyols which represent a small portion of total polyol production.

Isocyanates are the other key raw materials along with the blowing agent used in the production of polyurethane foams. It is estimated that over 75 percent of the total production of isocyanate in 1973 (871 million pounds) was used in production of foams, including that exported. Total Isocyanate merchant sales in 1973 were $221 million or about 83 percent of total U.S. production. There are 10 producers of isocyanates; the two largest--

Mobay and Upjohn -- have an estimated 50 percent of total industry capacity for the two major commercial isocyanates.

There were about 1.4 billion pounds of flexible and rigid polyurethane foam produced in 1974. Rigid foam production was approximately 400 million pounds and flexible polyurethane foam production was over 1 billion pounds. The total value of urethane foam products was approximately $1 billion in 1973.

Major producers of flexible polyurethane foam are E.R. Carpenter, Diamond Shamrock, Firestone, General Motors, General Tire and Rubber Company, Reeves Brothers, Goodyear, Sheller-Globe, Tenneco and Textron. These 10 companies account for 70 percent of total flexible polyurethane capacity; the balance is accounted for by 30 to 40 smaller producers. There are over 100 companies which are manufacturers of rigid polyurethane foam. The end-use pattern for rigid and flexible polyurethane foam is given in Table VI-32.

The number of companies producing and distributing the polyurethane foam end products is extremely large and diverse. Also, there is a large amount of overlap between foam manufacturers and end product manufacturers. Since there are many small producers of rigid and flexible polyurethane foam and foam products, the profitability and financial capability of smaller producers may limit their ability to convert to alternative blowing agents. The potential impact on this industry sector requires further analysis.

Approximately 32,000 people are employed in foam product manufacture. This estimate is based on employment figures for the industry which are

Table VI-32. U.S. CONSUMPTION OF POLYURETHANE FOAM - 1973

Category	Flexible (percent of total use)	Rigid (percent of total use)
Building insulation	-	38
Appliances	-	20
Transportation	33	14
Furniture	38	15
Industrial insulation	-	5
Carpet underlay	8	-
Marine flotation	-	3
Bedding	10	-
Textile laminates, packaging	4	-
Other	7	5
Total	100%	100%

Source: Arthur D. Little, Inc., estimates based on published data.

published in the Census of Manufacturers, 1972 and updated to 1973 assuming a constant output per employee. Industry sources estimate that 15,000 people are employed in foamed plastic manufacturing and another 10,000 in raw material manufacturing for a total of 57,000 people involved in activities related to the use of fluorocarbon blowing agents.

7. Solvents

The chlorocarbons and the fluorocarbons have important solvent applications. The major categories for the use of solvents are in metal cleaning and textile cleaning and processing. Metal cleaning involves a wide range of products including transportation equipment, electrical machinery, primary metal products and jewelry. There are two basic methods of cleaning metal -- cold cleaning and vapor degreasing. Vapor degreasing involves placing the part to be cleaned in the vapors of a boiling solvent. Trichloroethylene is particularly suitable to this method and is employed in the majority of vapor degreasing operations. However, because of air pollution considerations, methyl chloroform is being utilized to an increasing extent in addition to perchloroethylene. Perchloroethylene is principally used for dry cleaning, and processing and finishing textiles. Besides its cleaning capability perchloroethylene has the additional properties of being nonflammable and easily recoverable. To a limited extent F-113 and ethylene dichloride are also employed as dry cleaning agents.

Chloroform and trichloroethylene find small applications as extraction solvents. Trichloroethylene is used in decaffeinating coffee, and chloroform is an extraction solvent for vitamins, penicillin, antibiotics and flavors. Other chlorocarbons are widely used in laboratory-scale solvent and extraction applications.

According to industry estimates, total employment in plants utilizing fluorocarbon solvents is 160,000.

VII. INITIAL ECONOMIC IMPACT ASSESSMENT

A. INTRODUCTION

The preceding chapters of this report have defined the current uses of fluorocarbons and chlorocarbons, estimated their atmospheric emissions, and described the primary U.S. producing and consuming industry sectors. The transition schedules for each of the major production and consumption sectors in the face of restrictions in the use of fluorocarbons and chlorocargons have also been developed. This chapter identifies and describes the economic dislocations likely to be experienced in the United States if regulations are promulgated to reduce U.S. halocarbon emissions.

A set of potential regulatory strategies are identified, followed by a summary of the key information from the previous chapters. The approximate emission reduction resulting from each regulatory option is also shown. The final section of this chapter describes in a qualitative way the effects on each of the industry sectors which would result from implementing each of the 18 regulatory alternatives.

The purpose of this initial economic impact assessment is to identify where impacts are likely to occur under the various alternatives and to estimate the relative magnitude of the impacts. This report does not attempt to project price increases or job losses, for example, as would be done as part of a more extensive examination of potential economic impacts on particular sectors.

There are, however, some general comments which can be made about the economic effects of restricting the use of the fluorocarbons and chlorocarbons. Because the current uses of the chemicals exist in price- and performance-competitive environments, one can generally say that for a given product performance, the current use of the chemical is the least costly product for satisfying the total need as perceived by the consumer. Restrictions in their use would require present consumers to shift to their next best alternatives which would either be more expensive or perform less satisfactorily. The alternative may satisfy the primary needs of the user but may not maximize total satisfaction. In some cases, a consumer shift to less satisfactory products may also be a shift to less expensive products. But generally one can say that a restriction in the use of a high volume chemical will result in substitution by higher priced products and some reduction in consumption. Even without a reduction in consumption, total consumer utility may decline.

The price effects of restrictions on the use of fluorocarbons and chlorocarbons are confused because the substitute products would in many instances be less expensive, though they would not provide the same product performance. The non-aerosol antiperspirant and hair spray products are generally less expensive, as are many of the alternative solvents and blowing agents. Lower solvent or blowing agent costs may be outweighed by higher equipment or operating costs.

The price increases resulting from restrictions on the chemical use or production would be caused first by having to use more expensive substitute products to achieve the same results, and secondly by increased prices of the fluorocarbons and chlorocarbons themselves as a result of lower production levels.

There is the potential for job losses as a result of restrictions in a chemical's use. However, simply counting jobs may not adequately reflect disruptions resulting from the restrictions because the additional production of alternate products minimizes the employment impact. A ban in fluorocarbon production could result in an increase in the total number of jobs associated with producing the substitute products and performing the function now performed by the fluorocarbons. The next best product including chemical production, refrigeration applications, propellant applications, etc. may be less efficient in labor utilization than the present one and may require more labor hours to achieve the results now achieved using the fluorocarbons. While the total change in jobs may not be a good measure of economic impact, identifying the jobs lost and those gained could be a useful indicator of impact. Since sufficient analysis has not been conducted to quantify the jobs impact, this report has avoided listing jobs to be "impacted." Such impacts could range from job losses to simply learning to work with new products or chemicals. Until such impacts can be better defined, their discussion does not give great insight into the effects of the regulatory strategies.

The secondary and tertiary impacts of both price increases and job losses/gains is an important and often neglected dimension of economic impact. The one job lost/gained at a chemical manufacturer could result in two jobs lost or gained through multiplier effects. Because this report is directed at identifying primary impact areas, no attempt has been made to estimate these secondary impacts, though they should be estimated as part of a more complete economic impact analysis.

This report concerns the economic impacts or costs of undertaking various steps to reduce fluorocarbon and chlorocarbon emissions. The economic benefits of such reductions are not considered. In order to justify or mandate the economic disruptions which would result from restrictions in fluorocarbon or chlorocarbon use, the societal benefits flowing from these restrictions should be well understood. Conducting this preliminary economic impact assessment does not imply that substantial benefits would result from restrictions in the chemical usage. The question of whether the ozone layer is threatened has not been examined nor has the question of what would be the economic penalties (costs) of different reductions in the ozone layer.

While considering the economic impacts of the different regulatory strategies, one should bear in mind that a statement that a current use of fluorocarbons or chlorocarbons can be switched to a substitute product is not a statement that it should be switched without strong justification. Even though refrigeration systems, for example, would continue to be made and jobs may not be lost under a conversion to another refrigeration system, the society pays real and significant penalties for an imposed conversion. Simply because of higher refrigeration and air conditioning prices, fewer refrigeration and air conditioning products will be bought and less money will probably be available for purchasing other products. Thus, it is imperative that potential economic impacts be broadly conceived to include productivity effects, inflation effects, balance of payment effects, environmental effects, and not simply job losses or plant closings. And, in addition, the corresponding benefits of the proposed regulations which have not been considered in this report must be well understood before regulations are promulgated which would result in substantial economic disruption.

This economic impact assessment considers only the effects on the U.S. economy of restrictions on U.S. fluorocarbon and chlorocarbon emissions. If the ozone layer is threatened by these emissions, it is a worldwide problem and one which restrictions on U.S. emissions alone cannot solve. United States fluorocarbon and chlorocarbon atmospheric emissions now account for one-half of world emissions and the U.S. share will diminish in the future. If substantial reductions in worldwide emissions are necessary, other fluorocarbon- and chlorocarbon-using countries must also act to reduce atmospheric emissions of these compounds.

B. REGULATORY OPTIONS

1. Introduction

Through discussions with the EPA, nine regulatory options have been defined which are designed to reduce fluorocarbon and chlorocarbon emissions to the atmosphere by four different amounts on three different time schedules. These potential regulatory strategies have no official standing. They are only intended to identify a range of alternatives and to enable a more specific discussion of potential disruptions in the U.S. economy resulting from the options. Other regulatory actions are possible and will certainly be considered if a decision is made to reduce emissions.

2. Chemicals Considered

The following regulatory options assume that a limited number of critical uses exist which result in relatively small losses to the atmosphere and which would not be banned even if all other fluorocarbon and chlorocarbon uses were banned. Such critical uses, for which there are no adequate substitutes, could include products used in inhalation therapy or products used for fire control in aircraft. Since current theory indicates that a low level of atmospheric emissions may be acceptable, it is unreasonable to assume that the banning of such critical uses is a viable regulatory option. People would be exposed to high immediate health risks without any compensating reduction in damage to the ozone layer.

In describing the regulatory options and the resulting economic dislocations, it is specifically assumed that the critical uses will not be affected (except by higher product prices) by any of the options.

The timing of the various alternatives assumes that at some point in the next one to two years a decision will be made to execute a strategy for reducing emissions. The options discussed here and the resulting scenarios begin at the point the decision is made. If there are extensive delays before a decision is made, the affected industry sectors will have more time to prepare their response and the resulting economic disruptions could be lessened to some extent.

The current usage of 15 fluorocarbons and chlorocarbons has been discussed in this report. In order to make a general discussion of economic impacts manageable, the chemicals considered have been limited to two groups with relatively long atmospheric life times and relatively high production levels:

Chemical Group 1 (atmospheric lifetime greater than ten years)

Fluorocarbon 11

Fluorocarbon 12

Carbon tetrachloride

Chemical Group 2 (atmospheric lifetime of one to ten years)

Fluorocarbon 22

Methyl chloroform

These two chemical groups are considered in two combinations:

Chemical Use or Production Restriction Alternatives

Restricted Chemical Set A

Restrictions on Chemical Group 1

No Restrictions on Chemical Group 2

Restricted Chemical Set B

Restrictions on Chemical Group 1

Restrictions on Chemical Group 2

3. Definition of Regulatory Options

Nine regulatory approaches have been defined ranging from a ban of all uses of the chemicals after six months to a ban of propellant uses after six years. Each of the nine approaches is applied to Restricted Chemical Sets A and B for a total of 18 regulatory options.

The following nine regulatory approaches have been considered:

1. Ban All But Replacement Uses of Controlled Chemicals After Six Months

All direct uses of the controlled chemical and all uses in new products (Restriction Set A or Restriction Set B) would be banned six months after the issuance of the order (except limited critical uses). No new aerosols or air conditioners could be made with the chemicals, but the recharging of existing air conditioners and refrigeration equipment would be allowed.

2. Regulate Non-Propellant Uses and Ban Propellant Uses After Six Months

Design specifications would be promulgated requiring the upgrading of refrigeration/air conditioning, and solvent and blowing agent equipment and refrigeration/air conditioning service techniques in order to increase recovery of emissions now lost to the atmosphere. Use in propellant applications would be banned at the end of six months.

3. Do Not Regulate Non-Propellant Uses and Ban Propellant Uses After Six Months

No new controls would be placed on non-propellant uses of the chemicals, but the use of them as propellants would be banned at the end of six months.

4. Institute Government Control of Total Chemical Production After Six Months

The Federal Government would take some action to limit total chemical production by the end of six months and let the market mechanisms allocate its uses. The first such alternatives would be to specify a total U.S. production and tax away the excess profits made when the product prices are bid up. Another alternative would be to impose a tax, such as $1.00 a pound, on the chemicals in order to discourage their use as propellants and introduce an economic incentive for increased recovery of emissions in other applications. An auction system for buying the right to produce a specified amount of the chemical is another mechanism which more precisely controls how much will actually be produced and allows the market itself to establish a "tax" in the form of the payments for production rights. A 50 percent reduction in production has been assumed for each of the five chemicals.

5. Ban All But Replacement Uses of Controlled Chemicals After Three Years

This is the same as Option 1 except that the ban goes into effect at the end of three years.

6. Regulate Non-Propellant Uses and Ban Propellant Uses After Three Years

The regulatory action is the same as Option 2 except that the restrictions go into effect at the end of three years.

7. Do Not Regulate Non-Propellant Uses and Ban Propellant Uses After Three Years

The only restrictions would be a ban of propellant applications three years after the regulation is issued.

8. Institute Government Control of Total Chemical Production After Three Years

One of the mechanisms for controlling total U.S. chemical production would be put into effect at the end of three years.

9. Do Not Regulate Non-Propellant Applications and Ban Propellant Uses After Six Years

The only controls under this option would be a ban on propellant applications six years after promulgation of the order.

Summary of Regulatory Options

Immediate Restrictions

1. Ban All But Replacement Uses of Controlled Chemicals After Six Months
    - Restricted Chemical Set A
    - Restricted Chemical Set B
2. Regulate Non-Propellant Uses and Ban Propellant Uses After Six Months
    - Restricted Chemical Set A
    - Restricted Chemical Set B
3. Do Not Regulate Non-Propellant Uses and Ban Propellant Uses After Six Months
    - Restricted Chemical Set A
    - Restricted Chemical Set B
4. Institute Government Control of Total Chemical Production After Six Months
    - Restricted Chemical Set A
    - Restricted Chemical Set B

Restrictions After Three Years

5. **Ban All But Replacement Uses of Controlled Chemicals After Three Years**

   Restricted Chemical Set A

   Restricted Chemical Set B

6. Regulate Non-Propellant Uses and Ban Propellant Uses After Three Years

   Restricted Chemical Set A

   Restricted Chemical Set B

7. Do Not Regulate Non-Propellant Uses and Ban Propellant Uses After Three Years

   Restricted Chemical Set A

   Restricted Chemical Set B

8. Institute Government Control of Total Chemical Production After Three Years

   Restricted Chemical Set A

   Restricted Chemical Set B

Restriction After Six Years

9. Do Not Regulate Non-Propellant Uses and Ban Propellant Uses After Six Years

   Restricted Chemical Set A

   Restricted Chemical Set B

C. REVIEW OF PRODUCTION AND EMISSION STATISTICS

The assessment of potential economic impact resulting from various regulatory options is based upon the information reported earlier in the report on the uses of the chemicals, potential substitutes, conversion timetables, and current emission rates. Information concerning the five chemicals considered in the impact analysis have been summarized in Tables VII-1 through VII-6.

Table VII-1 lists the 1973 U.S. production and major use categories for the five potentially controlled chemicals. Table VII-2 lists the estimated losses to the atmosphere of each of the chemicals from its major use categories. Table VII-3 disaggregates the use categories more finely than does Table VII-1.

Group I chemicals are principally used as intermediate chemicals, propellants, and refrigerants. Their intermediate chemical use is principally for the production of F-11 and F-12 from carbon tetrachloride. Any limitations on F-11 and F-12 would directly impact carbon tetrachloride production and vice-versa.

F-11 and F-12 are used equally as propellants. For refrigerant applications, F-12 is the predominant Group I chemical, while for use as a blowing agent, F-11 is the predominant Group I chemical.

Group II chemicals are used as solvents (principally methyl chloroform) and refrigerants. F-22 is primarily used as a refrigerant with additional markets as a chemical intermediate (fluorocarbon resins). Methyl chloroform also has applications as a chemical intermediate (i.e., vinylidene chloride), and as a vapor pressure depressant in aerosols.

Table VII-1. ESTIMATED ANNUAL U.S. USES OF POTENTIALLY CONTROLLED CHEMICALS - 1973
(millions of pounds)

Chemical	Production	Propellant	Refrigerant	Solvent	Blowing agent	Intermediate chemical	Other [a]
Chemical group 1							
F-11	334	237	18	small	53	-	3
F-12	489	249	168	-	10	-	79
Carbon tetrachloride	1,047	-	-	small	-	995	52
Subtotal	1,870	486	186	-	63	995	134
Chemical Group 2							
F-22	136	small	90	-	-	35	11
Methyl chloroform	548	-	-	384	-	44	120
Subtotal	684	small	90	384	-	79	131
TOTAL	2,554	486	276	384	63	1074	265

a. Includes exports.

Sources: U.S. International Trade Commission; Chemical Marketing Reporter; Arthur D. Little, Inc., estimates based on industry contacts.

Table VII-2. ESTIMATED U.S. ATMOSPHERIC EMISSIONS FROM POTENTIALLY CONTROLLED CHEMICALS - 1973
(millions of pounds)

Chemical	Production	Production, transport & storage losses	← Estimated annual emissions from use and disposal →					
			Propellant	Refrigerant	Solvent	Blowing agent	Use as intermed. chemical	Total
Chemical Group I								
F-11	334	3.3	237	11	small	29	-	280
F-12	489	4.9	249	131	-	7.5	-	392
Carbon tetrachloride	1,047	15.7	-	-	21	-	9.9	46
Subtotal	1,870	23.9	486	142	21	36	9.9	718
Chemical Group II								
F-22	136	1.4	small	59.5	-	-	small	62
Methyl chloroform	548	5.5	-	-	427	-	small	433
Subtotal	684	6.9	small	59.5	427	-	small	495
Total	2,554	30.8	486	202	448	36	9.9	1,213

Source: Arthur D. Little, Inc., estimates.

Table VII-3. DEFINITION OF USES OF POTENTIALLY CONTROLLED CHEMICALS - 1973
(millions of pounds)

Chemical consuming sectors	Chemical Group I			Chemical Group II	
	F-11	F-12	Carbon tetrachloride	F-22	Methyl chloroform
Propellants					
Hairspray	103	72	-	-	-
Anti-perspirant	86	114	-	-	-
Other	48	63	-	Small	-
Refrigeration					
Appliances	-	9	-	-	-
Mobile air-conditioning	-	72	-	Small	-
Room and unitary air-conditioners	-	-	-	37	-
Commercial chillers	18	79	-	52	-
Other	-	8	-	-	-
Solvent					
Metal cleaning and degreasing	-	-	-	-	384
Electronics, aerospace etc.	-	-	-	-	-
Other	Small	-	Small	-	-
Blowing Agent					
(breakout not available)					
Flexible polyurethane	53	10	-	-	-
Rigid polyurethane			-	-	-
Other			-	-	-
Intermediate					
F-11	-	-	628	-	-
F-12	-	-	367	-	-
Vinylidene chloride	-	-	-	-	44
Fluorocarbon resins (i.e.PTFF)	-	-	-	35	-
Other (including exports)	26	62	52	12	120
Total	334	489	1047	136	548

Source: U.S. International Trade Commission; Chemical Marketing Reporter; Arthur D. Little, Inc., estimates based on industry contacts.

Table VII-4 summarizes the dependence of various end use categories on the potentially controlled chemicals. The table shows those end use sectors which are most dependent on the Group I and II chemicals and, by inference, those sectors which would be more severely impacted by limitations on Group I and II chemicals. For example, under blowing agents, 81 percent of rigid polyurethane foam produced is dependent on Group I chemicals, while flexible polyurethane is only 49 percent dependent on Group I chemicals. This suggests that rigid polyurethane would be more severely impacted by limitations on Group I chemicals. Although alternatives appear to exist for use in the rigid foams, because of the high degree of dependence of the sector on Group I chemicals, further analysis of these alternatives is required. Another example is commercial refrigeration (Table VII-4) under the refrigeration end use sector. This sector is 90 percent dependent on Group I and II chemicals, and therefore may be severely impacted by limitations on Group I and II chemicals. However, the level of dependence suggests alternatives exist other than Group I and II chemicals. In addition, reciprocating air conditioning is only 10 percent dependent on Group I chemicals. If limitations were placed on only Group I chemicals, the potential impact on the sector would be reduced.

Table VII-5 summarizes the consuming industry response times developed in Chapter V. The three primary types of responses to chemical use restrictions are emission reductions, substitute products, or substitute chemicals.

With the exception of aerosol applications, for which emission reductions are not an alternative, most current uses of the chemicals could

Table VII-4. DEPENDENCE OF USE CATEGORIES ON POTENTIALLY CONTROLLED CHEMICALS - 1973[a]

Chemical consuming sectors	Group I			Group II		
	Percent using F-11	Percent using F-12	Percent using carbon tetrachloride	Percent using F-22	Percent using methyl chloroform	Percent using all other fluorocarbons/ chlorocarbons
Propellants[b]						
Aerosol hairsprays	95	NA	0	0	0	5
Anti-perspirants	95	NA	0	0	0	5
Other	20	NA	0	Small	0	10
Solvents						
Metal cleaning	0	0	0	0	45	55
Dry cleaning	0	0	0	0	0	95+
Electronics aerospace	0	0	0	0	0	95+
Other	Small	0	Small	0	Small	95+
Chemical Intermediates						
Fluorocarbon resins	0	0	0	90-95	0	5-10
F-11	0	0	100	0	0	0
F-12	0	0	100	0	0	0
Vinylidene chloride	0	0	0	0	30-35	65-70
Blowing agents						
Rigid polyurethane	81 (includes F12)	NA	0	0	0	4
Flexible polyurethane	49 (includes F12)	NA	0	0	0	6
Refrigeration						
Appliances	0	100	0	0	0	0
Mobile air-conditioning	0	98	0	2	0	0
Room and unitary air-conditioning	0	0	0	100	0	0
Commercial refrig.	0	87	0	3	0	10
Commercial A/C						
-reciprocating	0	10	0	90	0	
-centrifugal	10	80	0	10	0	

a. Rows do not always total to 100 because all chemicals used in each use category are not included.

b. F-11 and F-12 are treated together in the column under F-11. Strictly speaking, F-11 is used as a vapor pressure depressant, in combination with F-12 as a propellant.

Source: Arthur D. Little, Inc., estimates based on industry contacts.

Table VII-5. CONSUMING INDUSTRY RESPONSE TIMES TO CHEMICAL USE RESTRICTIONS

Consuming industry	Emission reduction by equipment upgrading (years)	Primary response to ban of chemical use[a] (years)		Conversion substitute chemicals[b] (years)
Intermediate chemical applications	Not an option	2-7		5-10
Propellant applications	Not an option	1-2		4-10
Refrigerant applications [c]		to absorption	to F-22	
Appliances	2-3	4-6	3-4	5-11
Mobile air conditioners	3-4	Indefinite	Indefinite	5-11
Home air conditioners	2-3	3-5	zero	5-11
Commercial refrigeration	2-3	4-6	3-4	5-11
Commercial air conditioners				
- reciprocating	2-3	3-5	2-3	5-11
- centrifugal	2-3	2-3	1-3	5-11
Blowing agent applications				
Flexible foams	2-3	six months		six months
Rigid foams	2-3	3		4-9
Solvent applications	1	1-2		4-9

a. The primary response times are the elapsed times required for the consuming industries to introduce substitute products to meet the demand now satisfied by the controlled chemicals or products using the chemicals.

b. The conversion to substitute chemicals times are those required to develop new chemicals with properties similar to the banned compounds and to modify the products using the banned chemicals.

c. In the event of a ban of F-11 and F-12, most refrigerant applications would be converted to F-22. If F-22 is also banned, other refrigerants could be used or some products could be converted to absorption systems.

Source: Arthur D. Little, Inc., estimates based on industry contacts.

achieve significant emission reductions in two to three years. If the chemicals cannot be used, the consuming industries would have to switch to existing products not using the chemicals or redesign products to use substitute chemicals. For the refrigerant application in particular, comparable substitute chemicals do not exist and a five to eleven year period may be required to develop the substitutes and design new equipment to use them.

A comparable period may be required to develop comparable liquified gas propellants, but such a requirement is not as clear since some alternative propellants currently exist, though with somewhat different performance characteristics.

Table VII-6 was constructed to show the importance of the chemicals in determining final product prices. The table lists the percent of a final product selling price accounted for by the input chemical cost. Solvent uses are shown as not applicable since the solvents are "consumed" in the manufacture of a number of final products and represent a very small (and indeterminate) percent of the final product prices in many cases. An example is the use of these solvents to clean electronic computer components at one extreme, and use to dryclean clothes at the other extreme. The 20 percent of aerosol product cost represented by propellant indicates that a large increase in the cost of the propellant will have a significant impact on the aerosol price and thus potentially on the sales of the aerosol products. In contrast, the refrigerant represents 0.1 percent to 0.2 percent of the price of appliances. A major increase in refrigerant prices would have a very small impact on the appliance price.

Table VII-6. VALUE OF CHLOROCARBONS AND FLUOROCARBONS RELATED TO PRICES OF END USE PRODUCTS - 1973

Chemical	Consuming product	Cost of chemical/ price of product
F-11, F-12	Propellant applications[a]	
	hair spray	15-20%
	antiperspirant	20-25%
	Intermediate applications	
Carbon tetrachloride	F-11, F-12	35-40%
	Refrigerant applications	
F-11, F-12, F-22	appliances	0.1% - 0.2%
	mobile air conditioner	1-2%
	room & house air conditioner	0.2%
	commercial refrigeration	0.1% - 1%
	commercial air conditioning (chillers)	
	reciprocating	0.1% - 1%
	centrifugal	3%
	Solvent applications	N.A.
Carbon tetrachloride, Methyl chloroform, F-113		
	Blowing agent applications	
F-11, F-12		5%

[a] Based on manufacturer's price.

Source: Arthur D. Little, Inc., estimates.

D. ASSESSMENT OF ECONOMIC IMPACTS

1. Introduction

The objective of this section is to identify those industry sectors likely to be impacted by the regulatory options outlined in Section B of this chapter and to assess the relative magnitude of the impact.

Table VII-7 was constructed to summarize the results of the economic impact assessment. As described in Section B, nine possible control strategies have been considered for two groups of chemicals. An estimate has been made of the impact resulting from the 18 alternatives on 10 primary impact industry sectors. Estimates have not been made of changes in consumer prices, production levels, or job levels.

As a tool for categorizing the magnitude of economic impact, five levels of impact were defined:

Levels of Economic Impact

1. Severe Impact

A Severe Impact implies that most companies in the sector will be affected, at least to a moderate degree (some seriously), and more than 40 percent of the directly related business activity of which the chemical production or chemical consuming production is a part will be ended or significantly disrupted.

2. Substantial Impact

A Substantial Impact implies that some firms in the sector will experience at least a moderate and in some cases a serious impact, and a significant portion (greater than 10 percent but less than 40 percent) of the directly related business activity of which

Table VII-7. SUMMARY OF ECONOMIC IMPACT FROM REGULATORY OPTIONS

	Regulatory options		Impact sectors								
				Propellant applications				Non-propellant applications			
				Aerosol industry							
			Producers of basic chemicals	Fillers	Can manu-facturers	Valve manu-facturers	Marketers	Refrigeration & air conditioning manufacturers	Users of blowing agents (rigid foams)	Users of solvents	Users of chemical intermed.
6 mos.	1.	A	2-3	1	3	1	2	1	2	5	5
		B	2	1	3	1	2	1	2	3	3
	2.	A	3	1	3	1	2	4	3	5	5
		B	3	1	3	1	2	4	3	5	4
	3.	A	3	1	3	1	2	5	4	5	5
		B	3	1	3	1	2	5	4	5	5
	4.	A	3	1	3	1	2	4	3-4	5	5
		B	3	1	3	1	2	4	3-4	5	4
3 yrs.	5.	A	3	2-3	5	2-3	3	1-2	3	5	5
		B	3	2-3	5	2-3	3	1	3	5	3
	6.	A	3	2-3	5	2-3	3	4	3	5	5
		B	3	2-3	5	2-3	3	4	3	5	4
	7.	A	3	2-3	5	2-3	3	5	4	5	5
		B	3	2-3	5	2-3	3	5	4	5	5
	8.	A	3	2-3	5	2-3	3	5	4	5	5
		B	3	2-3	5	2-3	3	5	4	5	4
6 yrs.	9.	A	5	3-5	5	3-5	5	5	4	5	5
		B	5	3-5	5	3-5	5	5	4	5	5

IMPACT CODE[a]

1 - severe
2 - substantial
3 - moderate
4 - limited
5 - essentially none

REGULATORY SUB-OPTIONS

Chemicals controlled:

Sub-option A: F-11, F-12, carbon tetrachloride
Sub-option B: F-11, F-12, carbon tetrachloride, F-22, methyl chloroform

REGULATORY OPTIONS

1. Ban all but replacement uses of controlled chemicals after six months.
2. Regulation of non-propellant uses and ban of propellant uses after six months.
3. No regulation of non-propellant uses and ban of propellant uses after six months.
4. Government control of total chemical production after six months.
5. Ban all but replacement uses of controlled chemicals after three years.
6. Regulation of non-propellant uses and ban of propellant uses after three years.
7. No regulation of non-propellant uses and a ban of propellant uses after three years.
8. Government control of total chemical production after three years.
9. No regulation of non-propellant applications and ban of propellant uses after six years.

[a] See text of report for definition of these terms.

Source: Arthur D. Little, Inc.

the chemical production or chemical consuming production is a part will be ended or significantly disrupted.

3. Moderate Impact

A Moderate Impact occurs when a few firms in a sector will experience a moderate impact on sales or profits, and no more than a small portion (less than 10 percent) of the directly related business activity of which the chemical production or chemical consuming production is a part will be ended or significantly disrupted.

4. Limited Impact

The Limited Impact category includes those situations in which the regulations would impact firms in a sector or the production in the sector related to the controlled chemicals only through increases in product prices. If a reduction in a chemical's production or the imposition of a tax results in a large increase in the chemical's price, the resulting product price increase in sectors continuing to use the chemical may result in some unit sales fall-off. Equipment upgrading to reduce emissions to the atmosphere would also raise product prices and fall in this category if the regulation imposed no other limitations on continued production. While the magnitudes of these price and sales changes have not been defined, the instances when they may occur have been identified as Limited Impacts.

5. No Impact

The No Impact category covers instances when the proposed regulations would have essentially no impact on the firms or production of a particular sector related to the controlled chemicals. Very small price increases are possible under this category.

The economic sectors which could potentially be affected by the nine regulatory approaches can be divided into the production sectors (basic chemicals) and the consuming sectors. The producing sectors will be affected because a portion of their production will be ended or restricted. The consuming sectors can be further divided into the propellant applications (subdivided into fillers, cans, valves, and marketers) and the non-propellant applications. This division of the consuming sectors corresponds to the division among alternatives for reducing emissions to the atmosphere.

About 50 percent of the atmospheric losses are attributed to the aerosols, and there are no opportunities for continuing to use the fluorocarbons in aerosols but not allowing them to escape to the atmosphere. Thus, one regulatory option is to ban the use of fluorocarbons in aerosols or not to ban them. In the other consuming sectors, there are some opportunities for reducing emissions without banning the use of the chemicals. These emission reduction possibilities add a third regulatory opportunity for the non-propellant consuming sectors.

The restrictions are assumed to go into effect either at the end of six months or after three years. The ninth regulatory approach considers just a ban on propellant uses after six years.

Under each of the nine regulatory approaches are sub-options A and B. The A options consider restrictions on the production of only F-11, F-12, and carbon tetrachloride. Almost all propellant uses of fluorocarbons use F-11 or F-12, and the opportunities do not appear to be great for moving to other fluorocarbons as substitute propellants. About 95 percent of carbon tetrachloride is used to make F-11 and F-12 and thus the three chemicals must be considered together.

Under regulatory sub-option B, F-22 and methyl chloroform are restricted in addition to the other three chemicals. As far as propellant applications are concerned, there are no differences between the two options. If sub-option A is imposed, refrigeration and air conditioning producers can use F-22 (R-22 in refrigeration terminology) in many applications, though some design and equipment changes would be required. Under sub-option B, this opportunity will not be available and a conversion to another refrigerant or another cooling technology, such as absorption systems, may be required.

Methyl chloroform is a major solvent, while the other chemicals have only limited solvent uses. Therefore, only sub-option B has implications for the solvent applications of chlorocarbons, though important chlorocarbon solvents are not considered in the analysis. Under the regulation as proposed, most users of methyl chloroform would probably switch to a halocarbon solvent not being controlled, such as F-113. This opportunity substantially mitigates the potential impact of the regulations on the users in comparison with a broader ban on all chlorocarbon and halocarbon solvent uses.

Of the chemicals considered, only F-11 and F-12 are used as blowing agents. The economic impacts of sub-option B are therefore identical to A for the blowing agent uses. The producers of flexible foam appear to be able to convert to methylene chloride as a substitute blowing agent if restrictions are placed on the fluorocarbon blowing agents. Since the conversion could be effected in six months, the economic impact would only be seen in possible price changes. The producers of rigid foams have a much more difficult conversion problem, and for this reason only the rigid foam producers have been considered in the impact analysis.

The uses of the fluorocarbons and chlorocarbons as intermediate chemicals (raw material inputs) for the production of other final product chemicals were discussed extensively in Chapter VI. Carbon tetrachloride is an intermediate for the production of F-11 and F-12. When a fluorocarbon or chlorocarbon is used as an intermediate, the processing takes place in a closed system and the final product does not usually retain the same characteristics which potentially could affect the ozone. The emissions of fluorocarbons and chlorocarbons from uses as intermediates are about 1 percent of the tonnage used. However, ending the availability of the chemicals could have profound effects on the products using them. This potential for a large economic impact is obscured somewhat because, of the five chemicals considered in this economic impact assessment, only methyl chloroform and F-22 have significant uses as intermediates (excluding carbon tetrachloride uses in making F-11 and F-12).

Under the regulatory options as defined, sub-option A has virtually no impact on the users of fluorocarbons and chlorocarbons as intermediates because the three chemicals considered are not used extensively as intermediates. Under sub-option B, some economic impact would be experienced because methyl chloroform has some limited intermediate applications and F-22 is used for making fluorocarbon polymer. However, the economic impact of restrictions in the availability of these two chemicals would be much less than that of a broader ban on fluorocarbon and chlorocarbon products. Such a broad ban would have significant economic implications for complex, capital-intensive plants dedicated to products using the fluorocarbon and chlorocarbon intermediates.

2. Discussion of Regulatory Options

Option 1. Ban All But Replacement Uses of Controlled Chemicals After Six Months

A. Under this option, all new uses of F-11, F-12, and carbon tetrachloride, except a limited number of specifically identified critical uses, would be banned six months after the issuance of the regulation. Recharging existing refrigeration and air conditioning equipment would be allowed as would chemical production to meet this demand.

No aerosol products using F-11 and F-12 would be produced after the ban. Within six months, adequate supplies of substitute products will not be available, and the impact on aerosol marketers will be substantial. Until two to three years after the ban there will not be a restoration of the supply/demand balance with non-aerosol products replacing the F-11 and F-12 aerosol products. Even after three years, the current sales of aerosol products measured by units sold or dollar sales may not be restored. Some consumers who now buy the fluorocarbon aerosol products may not find the substitute products satisfactory for their purposes and thus may not switch. This could result in a permanent loss of market in some product categories. For example, some hair spray users may turn to other methods of maintaining their hair style such as pump sprays while others may find no product satisfactory and change hair styles.

The contract fillers of aerosol products and the valve manufacturers are highly dependent on aerosol sales. The fluorocarbons are used in about 50 percent of U.S.-produced aerosol products. Under this regulatory option, their activities would be even more significantly affected than the marketers. The sales of the fillers and valve manufacturers could decline by 50 percent when the ban took place. The introduction of substitute products over the following year will not be of much benefit since most of these products will not be in aerosol form. The potential for using compressed gas aerosols, such as compressed CO_2, and new valve designs was described in earlier parts of the report. In the event of a ban after six months, these potential substitutes, even if technically available, could not be brought on line as quickly as the existing non-aerosol products when production capacity simply needs to be expanded. Thus, under the most optimistic assumptions, a ban on using F-11 and F-12 in aerosols after six months would dramatically reduce the sales of fillers and valve manufacturers, and the reduction would continue for at least two years.

The can manufacturers would experience a moderate impact as a result of an end of fluorocarbon aerosol production. While all aerosol cans are 43 percent of general packaging cans, they were only 3.6 percent of total U.S. can production in 1973. About half of the aerosol cans would be affected by the ban. The introduction of the substitute products would not reduce the impact on can manufacturers since most of the substitutes would use glass or plastic containers.

For the manufacturers of refrigeration and air conditioning equipment, a ban on F-12 would have a severe economic impact. Only certain kinds of products are now made using F-22, and a total conversion to F-22 could not be achieved within six months. A majority of current production by the industry would probably end at the six months date and gradually come back over a three to five year period as the production of products using F-22 is expanded and producers convert their products to F-22, other refrigerants, or absorption technologies.

The F-11 and F-12 fluorocarbons are major blowing agents for both rigid and flexible foams. Methylene chloride can be substituted for the fluorocarbons in the flexible foams within six months. However, such a simple option does not exist for the rigid foams. The existing equipment for producing the rigid foam can be converted to use CO_2 and water, but the foam then loses much of its insulating properties. Without the fluorocarbon blowing agent, the foam will lose its competitive advantage over less expensive insulating materials such as fiberglass. If a ban on the use of fluorocarbons is imposed after six months, a substantial portion of the rigid foam production would end. There is no guarantee that the competitive problem of lower insulation can be overcome even after three years.

None of the three chemicals controlled under sub-option A have significant uses as solvents, and these consuming sectors would be unaffected by this regulatory option.

With the exception of carbon tetrachloride being an intermediate for the production of F-11 and F-12, the three chemicals do not have important intermediate uses, and there is no impact in this sector.

The impact of regulatory option 1A on the basic chemicals producers (F-11, F-12, carbon tetrachloride) has been categorized as moderate. In the first year of the ban, production of the three chemicals would be about 25 percent of the level of the previous year (5 percent for critical uses and 20 percent for recharging existing equipment). From the perspective of the total business activity of the producers and their chemical sales, the ban would not represent a major sales reduction. For all of the fluorocarbon producers, with the exception of the Racon Corp., the sales of all fluorocarbons account for less than 10 percent of chemical sales. Thirty-one percent of Racon's chemical sales are attributed to fluorocarbons and the ban would be important to that producer.

The end of F-11 and F-12 production would reduce current U.S. fluorocarbon production by 80 percent and clearly implies a very significant impact on that particular segment of the chemical industry. Since the producers are mostly major chemical producers for whom the fluorocarbons are a significant though small activity, the economic impact has been classed as less than if the viability of the firms were threatened by the ban.

Option 1B

Under this option, F-22 and methyl chloroform use would be banned at the end of six months in addition to F-11, F-12, and carbon tetrachloride.

The impact of this option on the propellant applications would be the same as under option 1A, since F-22 has only very small propellant uses.

The impact of this option on the refrigeration and air conditioning industry would be extremely severe. A large and important percentage of the current refrigeration and air conditioning equipment now uses F-22 and it is a potential substitute in many applications if F-11 and F-12 are banned. If all three are banned in six months, most refrigeration and air conditioning equipment production would end for a period of two to three years while products using other refrigerants or an absorption technology are developed.

Methyl chloroform is a major solvent. However, the impact has been assessed as moderate because opportunities exist for using solvents not included in the ban, such as F-113. There will be some disruption for a period of six months to a year after the ban takes effect while processing equipment is modified and material compatability problems are worked out.

Methyl chloroform is also used by Dow as an intermediate for the production of vinylidene chloride, a plastic wrapping material. About 9 percent of methyl chloroform production is used as an intermediate. While substitute wrapping materials are available, the vinylidene chloride production facilities will not be able to be easily converted to other products.

The impact of this option on the basic chemicals producers can be viewed as similar to option 1A. For the three methyl chloroform producers, the reduced sales would be a fairly small change in total chemical sales.

Option 2. Regulate Non-Propellant Uses and Ban Propellant Uses After Six Months

A. Under this regulatory option, F-11, F-12, and carbon tetrachloride could be produced without limitation. However, their use as propellants would be banned (except in certain critical uses) and requirements would be issued for equipment upgrading to reduce atmospheric emissions from other uses.

The impact of this option on the aerosol industry would be identical to that of option 1A. There would be a major impact on the fillers, valve manufacturers, and marketers with opportunities for recovery by the marketers as substitute products are introduced.

For the refrigeration and air conditioning industry, the regulation could result in a small change in prices but probably no significant change in sales volume. It is not assumed that only reduced emission equipment could be sold after six months. A redesign period of about a year would follow issuance of the regulation, with routine production of the new refrigeration and air conditioning units commencing in about 2-3 years. The manufacturers would have to improve valves and fittings, and F-11 and F-12 could cost somewhat more. But the total change in product prices is expected to be less than 5 percent.

The economic impact of this option on the firms using the chemicals as blowing agents has been categorized as moderate. The technology for reducing emissions does not exist and could not be installed for two to four years. As mentioned above, there is some opportunity to use substitute products. As a caution, it is noted that in addition to the few large companies accounting for 70 percent to 80 percent of foam production, there are a large number of smaller firms who may have relatively more difficulty making the necessary investments.

Since the products are not used as solvents or intermediates, there would be no impact from this regulation within the solvent or chemical intermediate sectors.

The impact of option 2A on the basic chemicals producers is similar to that of 1A because the half of the annual production used in aerosols would be ended, and a major part of the makeup sales for refrigeration and blowing agent uses would be ended if their losses are reduced by equipment upgrading. The economic impact on the basic chemicals sector has been categorized as moderate.

Option 2B

Regulatory option 2B adds F-22 and methyl chloroform to the list of controlled chemicals. The economic impact of the regulation on the aerosol industry would be identical to that of option 1A and 1B, since the propellant uses of F-22 are very small.

The impact of the regulation on refrigeration and air conditioning manufacturers would probably be the same as under option 2A - small product price increases. The costs of upgrading equipment for using the fluorocarbons is not likely to justify shifting from F-11 and F-12 to F-22 under option 2A, nor are they likely to induce a shift away from all three fluorocarbons under option 2B.

For blowing agent applications, the economic impact of 2B is identical to 2A since the added chemicals are not used as blowing agents. The solvent uses will be affected because there will be additional costs of vapor recovery equipment when using methyl chloroform. There may in addition be some increases in the price of methyl chloroform if the vapor recovery efforts result in lower yearly sales, as they should. It is possible that imposing the vapor recovery requirements on methyl chloroform and not other solvents will result in current users substituting uncontrolled solvents for current methyl chloroform uses. The magnitude of this potential shift has not been evaluated, but it would result more from a perception by the solvent users of the cost of using the chemical rather than a significant impact on final product prices. The cost of the solvent is usually a very small part of the cost of producing products such as circuit boards and high quality metal products.

The use of F-22 and methyl chloroform as chemical intermediates will not be changed by the regulation except that the price of the chemical may increase as a result of lower production levels.

For basic chemical producers, the regulation will have a slightly heavier impact than 2A as a result of additional reduction in F-22 and methyl chloroform production. The overall impact can still be characterized as moderate.

Option 3. Do Not Regulate Non-Propellant Uses and Ban Propellant Uses After Six Months

A. Under this option, the use of F-11 and F-12 as propellants would be banned after six months, but no other restrictions would be placed on the use of the chemicals. Option 3A is equivalent to options 1A and 2A as far as reducing emissions from aerosol products and the economic impacts on the aerosol industry. The alternatives provide descending control of losses to the atmosphere from non-propellant uses of the chemicals and correspondingly lower economic impact.

The economic impact of the 3A option on aerosol fillers and valve manufacturers is again classified as severe. The marketers would experience a substantial impact and the can manufacturers would see a moderate impact. The reasons for this level of impact are identical to those discussed earlier.

The effect of the regulation on refrigeration and air conditioning products would be essentially zero. The cost of the refrigerants may increase some as a result of reduced production for aerosol uses. However, the refrigerant accounts for about one percent of the price of refrigeration products, and moderate increases in the fluorocarbon prices are not expected to significantly reduce refrigeration sales.

The impact of the regulation on blowing agent applications would be somewhat greater than the refrigeration case. F-11 and F-12 costs represent about 5 percent of foam product prices. While there would be no specific requirements on the industry in order to use the chemicals, higher product prices resulting from higher chemical prices could produce a small fall-off in foam product sales. This effect is not expected to be great since there are no close substitutes for the flexible foams and the rigid foams already have a price premium because of their unique insulating properties.

There are no significant solvent uses of the chemicals and there are expected to be no effects from the regulation among the solvent users. The same is true in the chemical intermediate use category.

Because the current atmospheric losses of the chemicals in non-propellant uses will not be abated as in option 2A, the production levels of the basic chemicals will be close to current levels minus the production now going to aerosols. The impact has been categorized as moderate for the sector.

Option 3B

Option 3B adds F-22 and methyl chloroform to the list of chemicals whose use as propellants would be banned. While F-22 has some very limited uses as a propellant, the use of the two additional chemicals can be regarded as not changing as a result of the regulation. The overall economic impact of option 3B would be identical to that of 3A.

Option 4. Institute Government Control of Total Chemical Production After Six Months

A. Options 4A and 4B are intended to represent the potential regulation by which the cost of using the designated chemicals would be greatly increased by direct or indirect taxes or by direct restrictions on the total production of the chemicals. The market would then be allowed to redistribute the use of the chemicals among the highest value uses and encourage the abatement of chemical emissions to the atmosphere.

Table VII-6 (earlier) listed the percentage of final product price represented by the cost of the chemical used in the products. The solvent applications are shown as N.A. (small). However, a sharp increase in the price of fluorocarbon and chlorocarbon solvents would encourage the recovery of vapors lost in use. Substantial efforts are now made to recover emissions of F-113, which is more expensive than methyl chloroform. The other category of uses to be most affected by higher chemical prices is the propellant application. About 25 percent of the product costs are now propellant costs. In order to achieve a 50 percent reduction in the production of F-11 and F-12, the cost of the products would have to be sufficiently high to discourage most of the current aerosol uses of F-11 and F-12. While the level of such a price is unknown, it is assumed for the purposes of this analysis that approximately a 50 percent reduction in the production of the controlled chemicals will be achieved and most of the aerosol uses will be ended or substantially reduced. Due to the nature of aerosols as convenience products, it will be very difficult to predict what demand response will be to particular price increases. A period of testing demand response at several higher tax levels may be required before sales decline sufficiently or producers stop making the products in the face of the government actions.

The attractiveness of using a high tax or a system of auctioning production rights is that it is easier to administer and no government body is forced to make decisions about more and less important uses of the chemicals. In addition, there do not need to be any enforcement agencies for assuring that equipment specifications are met or emissions are kept below some specified level.

Under option 4A, the aerosol industry would ultimately experience an impact similar to that of an outright ban of fluorocarbon uses in aerosols. There would be something of a transition period while the market adjusted, but eventually the production of aerosol products using F-11 and F-12 would be substantially reduced and the marketers, fillers, and valve manufacturers would have had their activity substantially impacted. The same sequence of industry responses would then ensue as under a formal ban of the propellants.

The refrigeration manufacturers would be least affected by the regulation because the cost of the refrigerant is such a small portion of the total product price. The cost of maintaining the equipment and replacing the refrigerant falls on the equipment purchaser, not the manufacturer. There is thus no strong incentive on the manufacturer to upgrade the equipment to reduce emission losses, even though the losses will be more expensive to make up. There is probably not sufficient incentive to switch from F-11 or F-12 to F-22 which is not controlled under 4A.

Users of the chemicals as blowing agents will be given a strong incentive to recover the emissions or switch to different blowing agents. There are opportunities for doing both and there is the additional possibility that the sales of the foam products will be reduced by price increases resulting from increases in the blowing agent costs. While none of the uses of the blowing agents will be directly restricted by the regulation, the potential for at least limited disruptions of the firms using the chemicals is sufficiently large to warrant a three to four impact classification. Price changes will clearly be seen and the loss of sales by the industry as a whole and smaller firms in particular is a possibility.

The chemicals covered by option 4A are not used as solvents and, thus, this category of firms will not be affected. The same is true of the intermediate chemicals category.

The total level of chemical production would be very similar to that under option 2A. The production of F-11, F-12, and carbon tetrachloride would be reduced by about 50 percent, and the impact on the producing firms can be described as moderate.

Option 4B

Option 4B adds F-22 and methyl chloroform to the list of chemicals having their total production controlled by government imposed taxes or production restrictions.

Among the consuming sectors, only chemical intermediate uses are expected to be influenced differently. The impacts of option 4B on the aerosol industry would be essentially the same as option 4A, since the added chemicals do not have large uses as propellants. The refrigeration manufacturers would not be additionally affected (though F-22 is an important refrigerant) for the same reasons as described above.

Because a large percentage of methyl chloroform production is used as a solvent, a large increase in its price is directly seen by consumers with some options for converting to alternative solvents. The result could be a major shift to chlorocarbon or fluorocarbon solvents whose prices are not increased. In most cases, the regulation will not measurably affect the users of methyl chloroform as a solvent, but their response to a price increase could affect the producers of the chemicals.

Option 5. Ban All But Replacement Uses of Controlled Chemicals After Three Years

A. Options 5, 6, 7, 8, and 9 are intended to test whether a delay in implementing a ban or restriction would lessen the economic impact while not exposing the Earth to unacceptable risks resulting from further possible damage to the ozone layer. During the three years following the announcement of the pending restrictions, the consuming industries would have an opportunity to convert to other chemicals or substitute products. For many of the users of the fluorocarbons and chlorocarbons, three years seems to be in the middle of the estimated conversion time range. There is a significant difference between the economic impact of a ban at the end of two years and one at the end of four years. The three year ban may not adequately show this difference.

Option 5A is identical to 1A except that the ban of the use of F-11, F-12, and carbon tetrachloride would not take effect until three years after the announcement of the ban. If regulatory option 5A is promulgated, the aerosol marketers will have time for an initial response with substitute products, though they may not be aerosol products. The impact on the marketers is classified as moderate because while their product line will undergo a drastic change and there probably will be revenue losses, their continuity of participation in their primary markets will not be interrupted.

The impact on the aerosol fillers and valve manufacturers has a range of uncertainty because it cannot be predicted with any certainty whether aerosol products will be available as substitutes after three years. The development of the manufacturing technologies and product testing is now underway for compressed CO_2 aerosols, and these products may be available within three years. There is also information to indicate the possible availability of substitute liquified gas propellants within three years. To indicate the most likely range of impacts, the fillers and valve manufacturers have been designated as experiencing substantial to moderate impacts. If substitute aerosol products are readily available, the impacts will be moderate. If they are not available, the impacts will be substantial. The substantial classification indicates that the potential exists for very serious curtailment of their activities, but the three year lead time will allow for some steps to reduce the effects. The can manufacturers are estimated to experience no significant impact because the three years will allow them time to adjust the utilization of their production capacity now dedicated to aerosols.

The refrigerant applications are categorized as experiencing a substantial impact from a ban at the end of three years. Under option 5A, the manufacturers could convert to F-22 or other refrigerants instead of F-11 and F-12. They would also have the option of converting to a different refrigeration system. For some refrigeration and air conditioning products, a conversion to F-22 could be well underway within three years, but production to fully satisfy demand might not be seen for an additional year or so. It is not now apparent how some types of equipment could be redesigned within three years without F-11 and F-12.

The rigid foam blowing agent applications of F-11 have been classified as experiencing a moderate impact. Alternative blowing agents can be used to make the rigid foams, but they lose part of their insulation capacity and thus their competitive advantage. The possibility exists that even with a three year lead time, the rigid foams will not be satisfactorily reformulated to maintain their current share of the insulating market. The participation of many smaller producers suggests that such an eventuality would impose a severe impact on these smaller producers.

There is no impact in the solvent or intermediate application categories since there are essentially no such uses of these three chemicals.

For the basic chemical producers, the impact of a ban after three years is less than that of an immediate ban. The reduced production of the three chemicals would be offset in a relatively minor way by increased production of substitute chemicals such as F-22. While three years would allow time for the companies to work on substitute chemicals for the current major markets, it is not likely that new chemicals can be tested and their production facilities brought on line within three years. The impact of option 5A on the basic chemicals sector is classified as moderate because the revenues from these products represent such a small percent of the producing companies' revenues. These impacts would be less than in option 1A, where only six months elapsed before the imposition of the ban.

Option 5B

Option 5B adds F-22 and methyl chloroform to the chemicals whose new uses will be banned at the end of three years. The primary effect of their addition is that F-22 is no longer available as an alternative refrigerant to F-11 and F-12 and the large usage of methyl chloroform as a solvent in metal cleaning and degreasing must be switched to another solvent.

Methyl chloroform has no uses as a propellant and F-22 has only very limited propellant uses. Therefore, the economic impact of option 5B on the aerosol-related industries is virtually identical to 5A. Since neither of the added chemicals is used as a blowing agent, the impact in that sector is also identical to 5A.

For the refrigeration industry, the impact of option 5B would be more severe than option 5A. With F-22 no longer available as a substitute refrigerant, the manufacturers would have to switch to alternative refrigerants or systems. The startup time for producing these new products would be three to five years for most applications. It is not now apparent what alternative technologies can be used for mobile air conditioners. It is possible that major parts of the refrigeration industry would have to shut down for a period of time if option 5B were promulgated. The impact has been categorized as severe.

Methyl chloroform is a major solvent. However, banning its use is expected to have at worst a small impact on product prices of those business activities using it as a solvent. Its use is primarily in more routine cleaning operations for which substitutes (though perhaps less satisfactory substitutes from a price or performance basis) can be found within the three year period.

Both F-22 and methyl chloroform are used as chemical intermediates. Ending their availability will have an effect on the final product producers. This impact has been classified as moderate because even though the production of the final products would be ended, the revenues from the final products are a relatively small part of the total revenues of the producing firms.

The impact on the basic chemical producers would be about equal to that under option 5A, and it is still classed as moderate.

Option 6. Regulate Non-Propellant Uses and Ban Propellant Uses After Three Years

A. Option 6A would require ending the use of F-11 and F-12 as aerosol propellants and improved recovery of current emissions to the atmosphere from other uses of the chemicals after three years.

The economic impact of this regulation on the aerosol-related industries would be identical to that under option 5A. There would be no impact in the solvent or intermediate categories since these chemicals have very small solvent uses and no intermediate uses, except carbon tetrachloride use for making F-11 and F-12.

For refrigeration applications, the manufacturers would be required to upgrade the refrigeration equipment to reduce refrigerant losses. The cost of these changes is expected to be small relative to the total cost of the equipment, but the regulation could result in higher product prices. The impact has been classed as limited.

The users of the chemicals as blowing agents are expected to experience a moderate impact, both becuase the price of F-11 and F-12 will increase and because the expense of vapor recovery equipment will not be incidental. The smaller producers may experience a relatively more substantial impact because the vapor recovery facilities could make their operations relatively more expensive than those of larger producers.

The basic chemical producers will experience an economic impact under option 6A slightly less severe than under 5A. In addition to the 50 percent production reduction as a result of the propellant ban, there would be at least another 10 percent reduction resulting from the reduced leakage in other uses. The impact has thus been classed as moderate, as it was for 5A.

Option 6B

Under this option, the impact on the propellant and blowing agent uses would be the same as under 6A. The chemical intermediate uses could experience a price increase for products using methyl chloroform if there is a major reduction in its volume of production.

The refrigeration industry would have to upgrade its equipment now using F-22 as well as F-11 and F-12. These changes would result in some increases in product prices.

Option 7. Do Not Regulate Non-Propellant Uses and Ban Propellant Uses After Three Years

A. The only requirement under this option is a ban on propellant uses of F-11 and F-12 after three years. The effects of the regulation on other consuming sectors would only result from possible increased prices of the chemicals as a result of lower production.

The aerosol-related industries would experience the same heavy impact under option 7A as under 5A. There would be no impact on the solvent or intermediate use categories.

The refrigeration industry would have to pay more for F-11 and F-12, but the cost of a refrigerant is usually less than one percent of final product prices. The impact is classed as essentially none.

The impact of option 7A on the basic chemical industry is expected to be moderate and equivalent to option 6A. A majority of the production of F-11, F-12, and carbon tetrachloride will be ended, but these revenue losses represent a small percent of producer chemical sales.

Option 7B

This option is virtually identical to 7A since F-22 has only very limited propellant uses and methyl chloroform has no propellant uses.

Option 8. Institute Government Control of Total Chemical Production After Three Years

A. Under option 8A, the federal government would either impose a limit on the total U.S. production of F-11, F-12, and carbon tetrachloride approximately equal to current use in propellants or tax the products sufficiently to reduce production to the same level. A limit on total production would result in price increases to a level similar to that with the tax. This regulatory approach would have its largest impact on the aerosol uses of the chemicals, since the propellant accounts for about 20 percent of the price of the aerosol product. If the aerosol producers continued to use F-11 and F-12 at the higher prices, the product sales would be limited to those willing to pay a much higher price. Beauty shops, for example, might be willing to pay twice the current price for hair spray. However, the objective of the regulation would be to end the use of F-11 and F-12 as propellants in the mass market aerosols.

Faced with the government-imposed restriction on fluorocarbon propellant availability, the marketers will undertake conversion strategies very similar to those under an outright ban of the products. The current production of non-aerosol products will be expanded, and compressed gas aerosols will be introduced. The impact of option 8A must be classed as very similar to that of the more direct bans of the use of the fluorocarbons as propellants.

The solvent and chemical intermediate use categories will experience no impact since the three chemicals are not used in these sectors.

The refrigeration and air conditioning manufacturers are projected to experience essentially no impact under option 8A. The manufacturers may improve the equipment to reduce emission losses, but this is uncertain since the cost of refrigerant replacement is borne by the purchasers and not the manufacturers.

The users of the chemicals as blowing agents will experience a strong incentive to switch to another blowing agent or install vapor recovery equipment. The current cost of F-11 and F-12 represents about 5 percent of the manufacturer's price of foam products. Increased blowing agent costs or vapor recovery costs can require small but important increases in foam prices. The three year delay in the regulation should allow for a non-disruptive transition and a limited impact.

The basic chemical and raw material producers will experience production curtailments similar to those under option 6A. The impacts have been classified as moderate.

Option 8B

Option 8B adds F-22 and methyl chloroform to the chemicals whose production is controlled by government regulation. Neither of these chemicals has significant use as a propellant. Under this option, there would be essentially no impact on the refrigeration manufacturers for the same reasons as cited above for option 8A. The higher prices would put a large incentive on users of methyl chloroform as a solvent to switch to another solvent or install vapor recovery equipment. The effect of either step could significantly increase the cost of using a solvent, but this cost is a very small part of the costs of metal working and other activities using the solvents, and essentially no impact is expected.

The impact of option 8B on the basic chemical manufacturers is expected to be moderate.

Option 9. Do Not Regulate Non-Propellant Uses and Ban Propellant Uses After Six Years

A. Option 9 is a test of whether a postponement of a propellant ban to six years will reduce the economic impact of the regulation.

It appears likely that after six years a compressed gas aerosol could be available as could an acceptable liquified gas propellant. The impact of option 9A on the aerosol fillers and valve manufacturers has been categorized as moderate to none, reflecting the possibility that the marketers may not find a satisfactory aerosol substitute at a competitive price and there may be a general shift to non-aerosol personal care products. There is not expected to be a significant impact on the marketers if they have six years to adjust to the regulation.

Option 9A is expected to have no significant economic impact on the other consuming sectors except a gradual adjustment to higher prices for controlled chemicals, particularly by the users of blowing agents, as the aerosol use of the chemicals declines.

Option 9B

The impact of option 9B would be identical to that of 9A because methyl chloroform is not used as a propellant and F-22 has only limited propellant uses. The addition of F-22 to the list of restricted chemicals would prevent its being substituted for F-11 or F-12 in current refrigeration and aerosol applications.

E. POTENTIAL EMISSION REDUCTIONS

Table VII-8 summarizes estimated U.S. emission reductions for F-11 and F-12 achieved through 1995 for regulatory options 1A through 9A. Table VII-9 shows the assumptions used in estimating the impact of the control options on fluorocarbon emissions. These emission reduction estimates consider the expected growth in demand for fluorocarbons as well as the timing for the regulatory options. The emission reductions are based on options 1-4 becoming effective in 1976, options 5-8 effective in 1979, and option 9 becoming effective in 1982.

Option 1A, which calls for a ban of new uses of F-11 and F-12, would achieve a 92 percent reduction in potential emissions over a 20 year time period (1976-1995). A 100 percent reduction would not be feasible because of emissions from existing refrigeration systems and because "critical" aerosol uses are not restricted under option 1A. Emissions from blowing agent and solvent applications are assumed to be 100 percent eliminated. An estimate is also made of the change in total emissions since the start of F-11 & F-12 production (1945 is used as the first year of significant production). The reduction of total potential emissions of F-11 and F-12 from 1945 to 1995 under option 1A would be an estimated 70 percent. Option 2A achieves an 82 percent reduction in potential emissions of F-11 and F-12 over the 1976-1995 period. Option 2A, which restricts "non-critical" aerosol uses and requires controls on refrigeration and blowing agent applications, has a lower level of emission reduction than option 1A because of the continued use, although at a restricted emission level, of F-11 and F-12 in refrigeration and blowing agent applications. It is assumed that 60 percent of emissions in refrigeration applications are

Table VII-8. U.S. EMISSION REDUCTION FOR F-11 AND F-12 ACHIEVED THROUGH 1995 WITH SELECTED REGULATORY SCENARIOS

Option	Percent reduction of F-11 and F-12 cumulative potential emissions over 1945 to 1995 period	Percent reduction of F-11 and F-12 cumulative potential emissions from 1976 to 1995	Rank
1A	70	92	1
2A	63	82	3
3A	53	70	6
4A	61	80	4
5A	63	83	2
6A	56	74	5
7A	48	63	8
8A	52	69	7
9A	38	54	9
No control	0	0	10

Assumptions:
1. Options 1-4 effective 1976, options 5-8 effective 1979, and option 9 effective 1982.
2. Five percent growth in demand for uncontrolled uses.
3. Propellant applicants--critical uses are an estimated 5 percent of total potential demand.
4. Refrigeration--5 year half-life assumed for controllable existing fluorocarbon emissions; only 60 percent of future emissions from refrigeration systems are controllable.
5. Foam blowing--assumed 50 percent reduction of potential emissions achievable with controls.

Source: Arthur D. Little, Inc., estimates.

Table VII-9. SUMMARY OF U.S. ANNUAL FLUOROCARBON EMISSIONS WITH AND WITHOUT CONTROL

Consuming sector	Percent of total F-11 & F-12 end use	F-11 & F-12 emissions with no control (million lb)			F-11 & F-12 emissions with control (million lb)								
					1A	2A	3A	4A	5A	6A	7A	8A	9A
		1976	1979	1982	1976	1976	1976	1976	1979	1979	1979	1979	1982
Propellants													
"Non-critical" use	95	540	630	725	0	0	0	70	0	0	0	100	0
"Critical" use	5	30	35	40	30	30	30	30	35	35	35	35	40
Refrigerants													
Preventable and recoverable use	57	90	110	125	80	80	90	90	95	95	110	110	125
Leakage not recoverable and refrigerant not recoverable at disposal	43	70	80	95	60	70	70	70	70	80	80	80	95
Blowing agents													
Preventable and recoverable use	50	20	25	30	0	0	20	20	0	0	25	25	30
Uncontrollable use	50	20	25	30	0	20	20	20	0	25	25	25	30
Solvents	0	0	0	0	0	0	0	0	0	0	0	0	0
Total		770	905	1045	170	200	230	300	200	235	275	375	320

Assumptions:
1. Existing uses of F-11 and F-12 in refrigeration have a 5 year half-life (F-11 and F-12 emissions from existing equipment after 5 years would be reduced by 50 percent).
2. 5 percent/year growth in total emissions of F-11 and F-12.
3. An estimated 60 percent of F-11 and F-12 emissions from refrigeration and 50 percent of F-11 and F-12 emissions as blowing agents are preventable and recoverable.

Source: Arthur D. Little, Inc.

preventable and recoverable and 50 percent of emissions in blowing agent applications are preventable.

Option 3 only restricts "non-critical" aerosol uses of F-11 and F-12, and as a result, only a 70 percent reduction in potential emissions is achieved between 1976 and 1995. The continued, uncontrolled use of F-11 and F-12 in refrigeration and blowing agent applications reduces the potential level of emission reduction achievable. Option 4A, which restricts production of F-11 and F-12, achieves a level of emissions similar to option 2A at an estimated 80 percent. In the first year of control (1976), option 4A will not achieve the same level of emission reduction as option 2A, assuming only a 50 percent reduction in production. However, in future years the assumption is made that a level restriction on production will eventually eliminate "non-critical" aerosol uses of F-11 and F-12, and will result in emission reductions in refrigeration and blowing agent applications. Refrigeration equipment would be upgraded to reduce vapor losses, and vapor recovery equipment would be installed at foam producing facilities. As a result, option 4A is expected to have a similar impact on emissions as option 2A in later years, although the level of emission reduction over the 1976-1995 period is slightly less because of the expected smaller impact on emissions in the earlier years of production control.

Options 5A-9A are identical to options 1A-4A, except the regulations become effective at a later date. The level of emission reduction in options 5A-8A is reduced in comparison to the equivalent option where controls are required in 1976 since no emission control is achieved during the 1976-1978 period. However, the overall impact on emissions of a three year delay in implementation of controls (over the 20 year period) is limited. For example, options 2A and 6A achieve 82 percent and 74 percent reductions in emissions respectively over the 1976-1995 period. This represents only a 10 percent increase in total emissions over the 20 year period.

Figures VII-1 and VII-2 show the estimated cumulative emissions of F-11 and F-12 over the 1945-1995 period under the regulatory options 1A-9A, in comparison with the estimated cumulative potential emissions, assuming there is no control during the same time period. The figures depict graphically the relative levels of emission reduction achievable with each of the nine regulatory options.

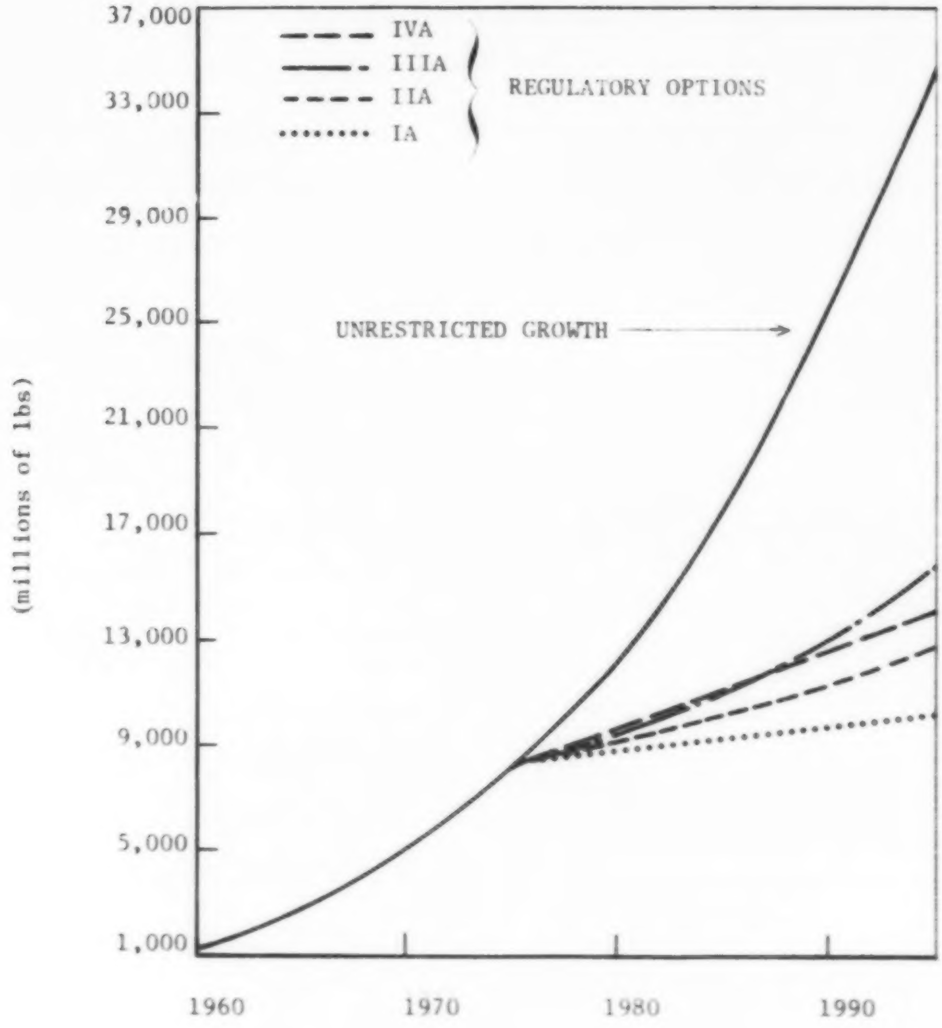

Figure VII-1. Cumulative U.S. Atmospheric Emissions of F-11 and F-12 Fluorocarbons Without Restriction and Under Regulatory Options IA-IVA

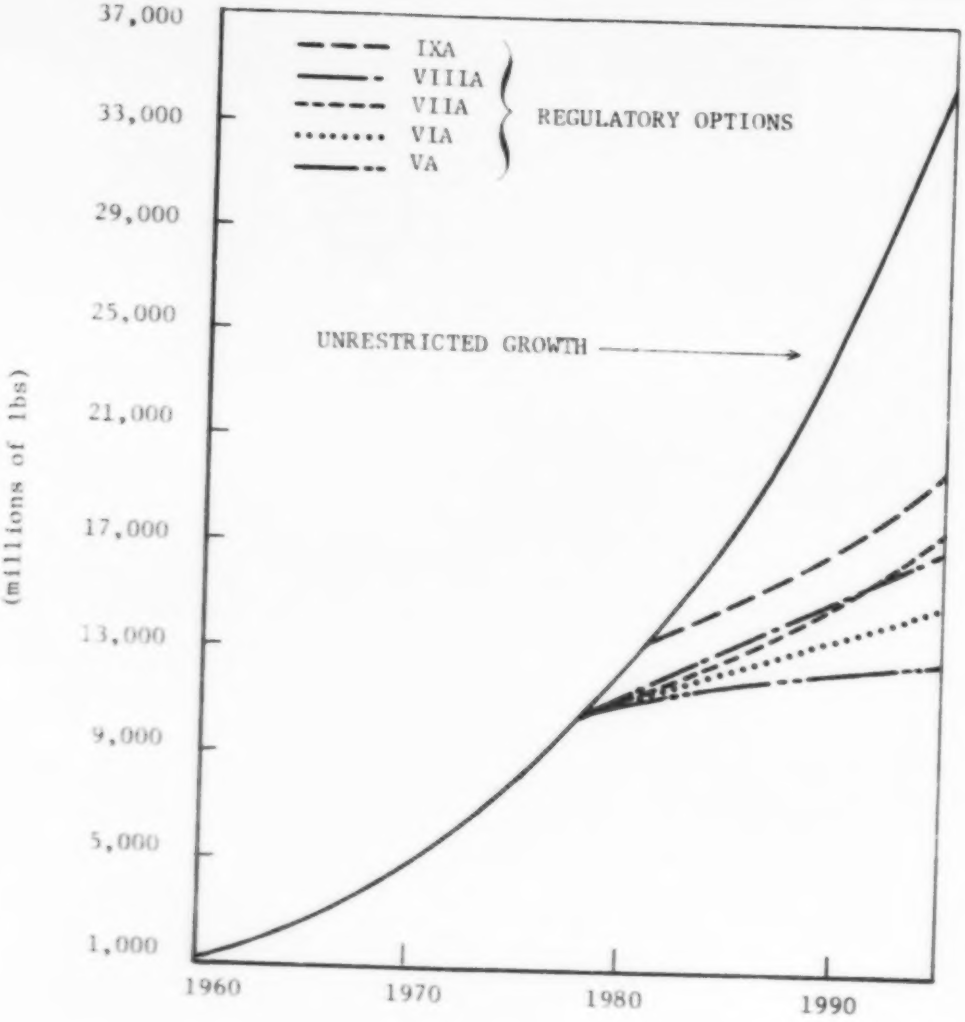

Figure VII-2. Cumulative U.S. Atmospheric Emissions of F-11 and F-12 Fluorocarbons Without Restriction and Under Regulatory Options VA-IXA

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